CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter deals mainly with the available literature on urban water supply and demand, wastewater treatment technologies, reuse option and cost, integrated urban water management (IWRM), application development of SDSS in field of urban water management and sustainability, and water sustainability index. Importance has been given on various aspects of SDSS as used in integrated urban water management.

2.2 Water Demand and Supply Perspectives:

The world's population is growing by about 80 million people per year and is predicted to reach 9.1 billion by 2050 (USCB, 2012). The World Health Organization (WHO) classifies the supply and access to water in four service categories. These categories are: (i) no access (water available below 5 lpcd); (ii) basic access (average approximately 20 lpcd); (iii) intermediate access (average approximately 50 lpcd); and (iv) optimal access (average of 100-200 lpcd) (Howard and Bartram, 2003). Considering the fact that various agencies recommend different quantities of requirement of water for domestic use, we have taken 135 lpcd consumption (or availability, as consumption is determined by availability) as a benchmark for identifying water deficient households. It must be noted here that there is no strong basis for this benchmark but it is a rough average requirement in order to maintain a minimum standard of health and hygiene (Shaban and Sharma, 2007). In India, The National Commission on Urbanization (1988) recommended that a per capita water supply of 90-100 litres per day is needed to lead a hygienic existence, and emphasized that this level of water supply must be ensured to all citizens (Ramachandraiah, 2001).

Water use (withdrawals and consumption) by different sectors is generally based on estimates, rather than actual measurements. These estimates indicate that freshwater withdrawals increased globally by about 1% per year between 1987 and 2000 (FAO, 2015a).Groundwater provides drinking water to at least 50% of the global population and accounts for 43% of all of the water used for irrigation (FAO, 2010). Worldwide, 2.5 billion people depend solely on groundwater resources to satisfy their basic daily water needs (UNESCO, 2012). An estimated 20% of the world's aquifers is being over-exploited (Gleeson et al., 2012), leading to serious consequences such as land subsidence and saltwater intrusion (USGS, 2013). Although funding for water infrastructure comes from government allocations, but many developing countries still depend on external assistance to fund water resources management and utilities. Over 50% of countries low on the Human Development Index (HDI) have reported that financing for water resources development and management from government budgets and official development assistance has been increasing over the past 20 years (UN-Water, 2012).

By 2050, global water demand is projected to increase by 55%, mainly from demands related to growing urbanization in developing countries (OECD, 2012a). In developing countries, because of rising population and increased development, the growth in supply is far lower and is currently trailing far behind the demand. As a result, it is expected that development will be significantly checked on the basis of water demand (Bouguerra, 1997).Cities will have to go further deeper (aquifer) to access water, or will have to depend on innovative solutions (alternate water) or advanced technologies to meet their water demands.

Currently, the water crisis appears to be due to poor water management. Chen et al. (2005) studied the water demand and supply for Heihe river basin, China. It is observed that water scarcity in the Heihe River Basin is not only caused by the physical condition, but is also the result of lack of integrated river basin management. Traditional integrated water resource management is easily defined as simultaneous assessment and management of water quantity and quality (Balabanis and Tiche, 2002).

Traditionally the water resource management has been taken up on basin scales. At macro level, ‘arid’ and ‘semi-arid’ areas are divisions. Developed and developing countries have different perception about objectives of watershed management. Developed countries usually focus on environmental concerns, while developing countries focus on resource generation and its management. The challenge on water management at micro level is to make reliable assessment of water demand and availability. The concept of integration is also applied on river basin scale at macro level before applying to urban or city scale.

Although water resource limitation is constrained for water supply, poor coverage and level of services of municipality have been seen as misconception in water supply and sanitation system (Cairncross, 2003) but increasing water stress cannot be ignored. Recently, non- conventional water created opportunity to support water supply which will release stress on urban water.

2.3 Wastewater Management: Treatment, Reuse and Cost:

Wastewater may be defined as a combination of the water carrying wastes removed from residences, institutions, commercial and industrial establishments from its sources point of generation. The discharge of untreated or partially treated wastewater into the environment results in the pollution of surface water, soil and groundwater. If it discharged into water bodies, wastewater is either transported to downstream or it infiltrates into aquifers, where it can affect the quality (and therefore the availability) of freshwater supplies. An estimated 80% of total industrial and municipal wastewater is released to the environment without any prior treatment, resulting in a growing deterioration of overall water quality with detrimental impacts on human health and ecosystems (WWAP, 2017). An estimated 90% of wastewater in cities in developing countries is discharge dun treated directly into rivers, lakes or the ocean (UNEP, 2010). According to UN-WWDR (2017), globally about 60% of people are connected to a sewer system (although only a small proportion of the collected sewerage is actually treated).

Accelerated urban growth poses several challenges, including dramatic increases in the generation of municipal wastewater. However, this growth also offers opportunities to break away from the past (inadequate) water management practices and adopt innovative approaches, which include the use of treated wastewater and by-products. In the recent times, municipal wastewater gets mixed with numerous other types of wastes. As a result its constituents have got changed and they need highly effective measures and treatment technologies for their treatment. WWDR-2017 mentioned that despite decades of regulation and large investments to reduce point source water pollution in developed countries, water quality challenges endure as a result of under-regulated diffuse sources of pollution.

Large-scale centralized wastewater treatment systems may no longer be the most viable option for urban water management in many countries. Other sanitation options, such as on-site systems, are well-suited to rural areas and low population density settings, but can be expensive and difficult to manage in dense urban environments. Decentralized wastewater treatment systems, serving individual or small groups of properties, have shown an increasing trend worldwide. They allow for the recovery of nutrients & energy, and save freshwater. Most cities do not have or allocate the necessary resources for wastewater management.

Many different treatment technologies for wastewater reclamation have been designed. Some technologies are highly efficient for the removal of pollutants present in the wastewater but their cost is very high. Therefore, a major shift have been observed in the reclamation strategies for wastewater from high-tech to environmentally sound, sustainable, low-cost and effective technologies based on ecological principles, namely ecological technology (Saha and Jana, 2003). Balkema et al. (2002) has also considered three dimensions for sustainability with some indicators for wastewater treatment assessment.

It is not easy to select the treatment technology as the wastewater standards, reuse of treated effluents in around particular urban area, social criteria and the environmental criteria are multitudinous in nature. In such complex problem decision support system is helpful as there various conditioning, multi-criteria decision support system is more suitable for these problems. Several measures for sustainable water resource utilization have been developed, of which wastewater reclamation and reuse is currently one of the top priorities (Anderson et al., 2001; Chu et al., 2004).

Potable use of sewage effluent basically is a practice of last resort, although unplanned or incidental potable reuse occurs all over the world where sewage effluent is discharged into streams and lakes that are also used for public water supplies, and where cess pits, latrines, septic tanks, and sewage irrigation systems leak effluent to underlying groundwater that is pumped up again for drinking. In-plant sewage treatment for direct potable reuse requires advanced processes that include nitrogen and phosphorous removal (nitrification/denitrification and lime precipitation), removal of organic carbon compounds(activated carbon adsorption), removal of dissolved organic and inorganic compounds and pathogens by membrane filtration (microfiltration and reverse osmosis), and disinfection. Even when all these treatment steps are used and the water meets all drinking water quality standards, direct potable reuse where the treated effluent goes directly from the advanced treatment plant into the public water supply system (pipe-to-pipe connection) is not recommended (Mitchell et al., 2003).People see this as a `toilet-to-tap' connection and public acceptance will be very low. Rather, to protect against accidental failures in the treatment plant and to enhance the aesthetics and public acceptance of potable water reuse, the potable reuse should be indirect, meaning that the effluent must first go through surface water (streams or lakes) or groundwater (via artificial recharge) before it can be delivered to public water supply systems. The surface water route has several disadvantages, including algae growth that can cause taste and health problems as some algal metabolites are toxic. To minimize algae growth, the wastewater may then have to be treated to remove nitrogen and phosphorous, which increases the reuse costs. Also, water is lost by evaporation and the water is vulnerable to recontamination by animals and human activities. These disadvantages do not occur with the groundwater route, where the water also receives SAT benefits. Groundwater recharge also enables seasonal or longer storage of the water to absorb differences between water supply and demand, and mixing of the effluent water with native groundwater when it is pumped from wells. Water reuse basically compresses the hydrologic cycle from an uncontrolled global scale to a controlled local scale.

Wastewater management presents numerous challenges. In cases where wastewater is discharged untreated, those affected may be geographically or temporally far away from the polluter. For this and other reasons, society must act collectively to promote human health and protect water resources from pollution. The related governance challenges involve legal, institutional, financial, economic and cultural issues (WWDR-2017).

2.4 Integrated Water Resource Management (IWRM):

Initially, river basin planning and management broadly includes environmental assurance, integrated optimal development of natural resources, integrate land and water management, decentralized management and planning to ensure developments within a basin (Borrow, 1998). River basin management requires evaluation in terms of standard water physical and chemical parameters and standards for various uses of the water for which an integrated modeling system prototype is designed which helps decision makers (Rousseau et al., 2000). Biswas (2004) sought that meso-to macro-scale projects with comprehensive analysis identified many problems in concept as well as its implementation. Finally, there is no common agreement on fundamental issues like what aspects should be integrated, how, by whom, or even if such integration in a wider sense is possible.

Chen et al. (2005) introduced water management includes the activities that aim to reduce water demand, improve water use efficiency and avoid the deterioration of water resources. However, a demand management offers sustainable water management solutions to face the increasing water scarcity and growing conflicts over water uses. Grigg (2008) defined integrated water resource management (IWRM) as a framework for planning, organizing and operating water systems (complexity) to unify and balance the relevant views and goals of stakeholders. Orr et al. (2007) emphasized the role of stakeholders to manage water related issues. It argues for more integrated management responses, characterized by collaborative and inter-disciplinary learning to manage the interdependencies, complexities and uncertainties of catchments as integrated systems. Davis (2007) added to promote coordinated activities in pursuit of common goals for multiple objective related to development and management of water founded in sustainable water resource systems. However, stakeholders are characterized by different political, decision-making and discursive power, and varied access to resources, tend to generate costs, benefits and risks that are distributed unevenly across spatial and temporal scales and across social groups (Molle, 2007).

Savenije and Zaag (2008) considered four dimensions in IWRM which need to be integrated i.e. the water sources, the water users, the spatial scale and temporal scale. It acknowledges the entire water cycle with all its natural aspects, as well as the interests of the water users in the different sectors of a society (or an entire region).Hence, it addresses both the natural and the human dimensions of water. Cai (2008) identified that holistic modeling as a better approach over systems techniques which depends on data availability and computing facilities. Molle et al. (2010) discussed two approaches for IWRM i.e. development approach and the ecosystem approach. The development approach focuses on harnessing nature and controlling water for human benefit through infrastructure development. On the other hand, ecosystem approach promotes restoring and maintaining the integrity of the water cycle and aquatic ecosystems. Volk et al. (2010) recommend to evaluate trade-offs among environmental measures and management alternatives while implementing decision tool for IWRM. Islam (2011) defined interrelations between water sources, demands, and economic benefits have to be considered in an integrated modeling framework to provide essential information for policymakers in their resource allocation decisions. However, that in order to implement the integration in water resource management for developed and developing countries, policies and projects need to be more sensitive to context-specific conditions (Beveridge and Monsees, 2013). Foster and Ait-Kadi (2012) stated that without clear vision of integration the major challenge of groundwater-resource sustainability cannot be effectively addressed. Vladimir et al. (2013) identified four analytical tools to integrate water resource components which are loosely coupled: (i) geographic information system; (ii) system dynamics simulation; (iii) agent-based model; and (iv) hydrologic simulation. Giordano and Shah (2014) acclaimed IWRM as more holistic approach for water management but pragmatic solutions to existing water problems shutting out alternative thinking. This is found that decision makers can do best by focusing on solutions to specific problems rather than on universal, water-centered approaches.

Apart from the quantitative and qualitative management economic aspects is also important during management. The cost-benefit analysis is simple way to predict the overall economic aspects. But complex nature of water always questioned 'how to measure benefits?' Till the date answer of this problem appears to be to make the current resources in more planned way.

2.5 Integrated Urban Water Management (IUWM):

Urbanization is a global phenomenon. The prime objective of urban water planners is to ensure the adequate water for human livelihood and all other activities. However, sustaining the pace of development for long terms without sacrificing the values of available natural resources for the next generation have to be the guiding principles in such planning. This includes a holistic consideration of water supply, water demand, wastewater treatment, reuse of treated wastewater, drainage and storm water management. Many efforts have been made to integrate the water cycle and ensure that urban design and planning properly incorporate the opportunities (Grigg, 2008).

At unban scales, the concept of Integrated Urban Water Management (IUWM) has been suggested. The proper management with zero liquid discharge at local or regional scale is considered as 'Integrated Urban Water Management'. Such a holistic approach requires not only supply management, but also demand management, water quality management, recycling and reuse of wastewater.

In urban systems, two water cycles are observed i.e. ‘Natural Water Cycle’ and ‘Anthropogenic Water Cycle’. Natural water cycle is well known phenomenon and considered that nature can balance its cycle whereas the anthropogenic water cycle is not even well defined but termed for used fresh water its reuse and disposal into natural system. Hence, there is an essential need to define and understand the anthropogenic water cycle and its proper management.

Bouwer (2000) has discussed the issues and challenges of increasing population with higher living standards, need safe drinking water, good quality municipal and industrial water and ever increasing sewage flow which will increase complexity for future water management. This includes economics, conflict resolution, public involvement, public health, environmental and ecological aspects, socio-cultural aspects, water storage, conjunctive use of surface water and groundwater, water pollution control, flexibility, regional approaches, weather modification, sustainability, etc.

Rijsberman and van de Ven (2000) have identified the sustainable water management in urban water systems as complex problem and suggested four basic approach to sustainability viz. carrying capacity approach, ratio-centric approach, socio-centric approach and eco-centric approach which concluded that acceptance of the solution by all stakeholders is highly important to the successful realization of a sustainable solution.

Mitchell (2006) identified benefit of an integrated approach to urban water systems which is potential to increase the range of available opportunities in order to develop more sustainable systems. He considered principals of IUWM summarized below:

1. All parts of the water cycle, natural and constructed, surface and subsurface, recognizing them as an integrated system.
2. All requirements for water, both anthropogenic and ecological.

3. The local context, accounting for environmental, social, cultural, and economic perspectives.
4. All stake holders must be included in planning and decision making processes.
5. Strive for sustainability, aiming to balance environmental, social, and economic needs in the short, medium, and long term.

The final findings state that there is still room for greater integration of the water supply, storm water, and wastewater components of the urban water cycle.

Bahri (2012), refined IUWM for future initiatives of planning and management from the demand-driven approach. The emphasis was given on quality concerns rather than only quantity which enforced urban water management to transform into integrated urban water management. The practical approaches adopted for green building cities that are inclusive, productive, well governed and sustainable.

Framework for Integrated Urban Water Management (IUWM) may include storm water management and rainwater harvesting, water conservation, water reclamation and water reuse, source separation as well as decentralization of water treatment and use of local groundwater. IUWM are multi-stakeholder process and needs to start with:

1. Evaluation of the actual situation involving all stakeholders.
2. Selection of a water supply and sanitation strategy and an inventory of the technological and non-technological options as future alternatives for the water cycle, where various possible changes in the use of technology, space and several socio-economic scenarios can be introduced.
3. Selection of the measures, including an evaluation of their costs and benefits under different development scenarios.
4. How to integrate these into the long-term planning of urban investments.

Arghyam, an initiative of NGO (2012), studied Mulbagal town Karnataka (India) based on IUWM principals with objectives:

1. Closing the urban water loop and integrating all aspects of water from source to sink.
2. Balancing the demand, supply, and resource availability.
3. People's participation in all stages.
4. Universal access to water and sanitation facilities.
5. Decisions are made at the lowest appropriate level – giving priority to managing water resources locally.

It is observed that immediate value of the IUWM was limited because it was not possible to incorporate the field lessons and challenges into the framework and align them precisely. However, the framework is comprehensive and covering all aspects of the IUWM cycle from scientific and financial models to engineering and community mobilization.

Okeola and Sule (2012) have evaluated alternatives for urban water systems by introducing three management options that are formulated on the prevailing nation's water supply sector and foreign countries models using multi-criteria decision making approach. These three options are (i) Public Ownership and Operation, (ii) Public Ownership and Private Operation and (iii) Private Ownership and Operation. The stakeholders have chosen option 1 i.e. Public Ownership and Operation as most contributing sustainable operation for an urban water supply service delivery under scrutiny of environmental, economical, technical, institutional, and socio-cultural criteria. The choice of option (i) reaffirms the stakeholder's opinion in the survey "They do not want government to abandon their responsibility in the water sector.

Mehta (2014) proposed 'Water Sensitive Urban Design and Planning' which includes demand management, reuse of grey water, reuse of treated black water (non-potable uses/environmental uses/industries), capture and use of storm water, and promote sustainable use of ground water.

Ulian et al. (2017) found that to maintain balance of water resource is most challenging problem. A methodology to evaluate cities' expansion based on the management of human consumption of water, structured on twenty-six indicators, designated by "Hydricity" indicators. For integrated water planning scheme, an index has been developed termed as Hydricity Global Level (HGL) and categorized by six qualitative levels i.e. A*, A, B, C, D, E. The HGL evaluation is based on a transformed dimensional value of qualitative or quantitative indicators into a non-dimensional parameter, allowing the results to be interpreted in a qualitative way and facilitating comparisons. This method admits that it is necessary to aggregate indicators, based on weighting systems.

2.6 Spatial Decision Support System (SDSS) and Urban Water Management:

Geographical Information System is considerably more than what most people would think of as a single computer program (Zhu et al., 1996). The other capabilities along with analytical capabilities make the GIS as a Decision Support System (DSS). DSS is a computer system, hardware and software, designed to support decision makers interactively in thinking about and making decision about relatively unstructured problems(Walker and Zhu, 2000).A DSS provides a framework for incorporating modeling capabilities with database resources to improve decision-making processes. Decision makers can interact with the system using intuitively designed easy-to-use Graphical User Interfaces (GUI). Walsh (1993) defined the integration of GIS with DSS and termed it as spatial DSS (SDSS).

In the context of water management, there are several DSS and SDSS proposed and implemented by the scientific community and government projects in various sectors of water i.e. watershed management, urban and rural water demand and supply management, storm water management, wastewater collection and treatment, municipal and industrial treated wastewater reuse etc.

Mitchell et al. (2001) have developed an application namely Aqua cycle. It is a water balance model which includes representation of water flows through the urban water supply, storm water, and wastewater systems. Its daily time step provides temporal distribution of the flows, and enables comparison of the different components of the urban water demand. Aqua cycle was tested using data from the Woden Valley urban catchment in Canberra, Australia and found able to satisfactorily replicate its water supply, storm water and wastewater flows. An approach to reduce pressures on water supply by reuse of storm water and waste water management, within the urban area for low quality water demands. The advantage of this is to reduce the quantity of high quality water imported into an urban area and reduce storm water and wastewater discharged to streams and receiving waters. Aqua cycle described a clearer picture of the resources available, and the possibilities of these alternative sources of supply.

MULINO-DSS (mDSS) has been developed under European water directives whose results were based on socio-economic and environmental modeling based on Driving force–Pressure–State–Impact–Response framework (DPSIR). The finding shows that trade-offs are envisaged between potentials for practical implementation and the software’s complexity (Giupponi et al., 2004).

Mitchell and Diaper (2005) have developed an application namely Urban Volume and Quality (UVQ) under prospects of alternative water servicing options in terms of environmental and performance requirements. UVQ has been designed to simulate the integrated water system within an urban area and to estimate the contaminant loads and concentrations and the volume of the water flow throughout the urban water system, from source to discharge point. It also linked the rainfall-runoff network and the water supply-wastewater network through processes such as the irrigation of gardens and open space, storm water inflow and infiltration in the wastewater system, and groundwater extraction for water usage amongst others. In this modeling approach, integration and complete water cycle representation are the primary goals, rather than complex modeling of water and contaminant flows. It was assumed that users are aware of the assumptions and simplifications made within the model and applications; UVQ provides a valuable insight into potential for alternative water servicing, the potential impacts of implementation, and the performance requirements of treatment processes to achieve reuse and environmental quality goals.

Hidalgo et al. (2007) developed a decision support tool for reuse of treated wastewater to conclude alternatives that can be generated and evaluated against criteria such as cost, safety, environmental constrain, technical and social factors.

Makropoulos et al. (2008) have developed a decision support tool known as Urban Water Optioneering Tool (UWOT) to facilitate the selection of combinations of water saving strategies and technologies and to support the delivery of integrated, sustainable water management for new developments. Water management solutions for new residential developments should be based on sustainability considerations i.e. social, economic and environmental implications. This concept implemented on household block scale using genetic algorithm for optimization of well-planned towns or city. Two scenarios developed as a proof of concept of the tool's operation. The benchmark scenario, or Business As Usual (BAU), resembles residential developments using conventional, water intensive technologies. The scenario uses population and household data specific to Elvetham Heath and makes use of conventional technologies at the household level assuming no rainwater harvesting, grey water recycling. The Benchmark scenario, calculated over a simulated period of 10 days, is approximately 168 liter per capita per day (lpcd). This was approximately 10% higher than the 150 lpcd which is identified as a typical value for the UK. The Water Save scenario is based on the same base data (number of houses, occupancy, pervious and impervious areas of the Elvetham Heath case study), but uses water saving technologies at the household level; for example, dual WC cisterns and low flow showerheads, which are selected (manually) by the user. This scenario is realistic as the technologies employed are already developed and both the market and society are progressively adopting them. Similar to the benchmark scenario, the Water Save scenario assumes no centralized grey water recycling and rainwater harvesting and the only source of water is the WSP external supply. The Water Save scenario shows a decrease in demand for potable water, indicating a per capita consumption of 109 lpcd, which is in agreement with what literature suggests as possible following the installation of water saving devices.

City Water Balance (CWB) is simulation tool developed within SWITCH as part of the city water integrated knowledge base system/decision support system. CWB is a scoping tool developed to allow the rapid assessment of alternative water management strategies for a city. The tool outputs indicator data on water demand, quality, energy consumption, and simplified life-cycle cost. The data requirements of CWB allow to be established a model quickly from extant spatial mapping. The framework includes spatial characterization, temporal resolution, water supply, runoff, local water management options, groundwater and surface water, contaminants, energy and cost (Mackey and Last, 2010).

2.6 Urban Water Balance and Sustainability Evaluation:

Recent developments in integrated water management, ecosystem services and multifunctional land use provide new opportunities for ‘getting more for less’. These can range from seeing all forms of water as a resource, exploiting opportunities to contribute to the green and blue infrastructure agendas, resilience to climate and other changes. A water-sensitive urban design can deliver opportunities; mitigate the urban development challenges; implement and support institutional, regulatory and practical opportunities (Ashley et al., 2013).

For a given urban set up, the annual input of water source includes intake from running sources (such as rivers) and storage from rainfall in terms of surface and ground water reserve (which forms part of storm water management). Water requirements for domestic supply, industrial, commercial and other development activities constitute the demand side of it. Wastewater generation, collection, treatment, reuse and disposal have direct bearing on quality of fresh water resources. The development planning of area very much depends on the water balance available for the purpose. Proposals of new developments, such as townships, thermal power plants or alike, where availability of water is an essential component, may be considered only when the urban geography and hydrogeology support the area as ‘water positive’. After use, if the generated wastewater is collected and treated, keeping in mind various reuse potentials in the area, the fresh water demand reduces significantly and pollution of fresh water resources is prevented. This broadly forms the system of Integrated Urban Water Management (IUWM). Water conservation and water recycling measures are key elements in integrated urban water planning (Anderson, 2000). The main purpose to integrate various components of urban water systems are to provide secure water, reducing impacts on environment, improvement of water governance and system-wide performance (Maheepala, 2010). It includes both urban water flows (potable water, wastewater and runoff), as well as their integration through recycling schemes (greywater, reclaimed water and rainwater harvesting) (Bahri et al., 2016).

Dublin statement (1992) has emphasized that fresh water is a finite and vulnerable resource and failure to recognize the economic value of it in the past and has led to wasteful use and environmental damage. This was an occasion when water has been considered as valuable resource and the concept of water sustainability emerged.

In broad, there are three types of sustainability i.e. social, environmental, and economic. They are compared by many earlier studies account other dimensions for the further refinement. Quantitatively, safe yield of water is commonly defined as the attainment and maintenance of a long-term balance between the amount of ground water withdrawn annually and the annual amount of recharge (Robert Goodland and Herman Daly, 1996).

Robins et al. (1999) has discussed that sustainable water management can contribute to the preservation and protection of wetlands. Because it maintains high water quality and quantity conditions, fulfills the present and future water demands and minimizes potential environmental impacts. Concept of water management applied in European countries in late 60's and this has played a significant role in the improved water conditions encountered in most European countries nowadays.

Balkema et al. (2002) developed indicators for the sustainability assessment of wastewater treatment systems. Economic, environmental, social-cultural criteria are considered for sustainability evolution.

Zacharias et al. (2003), studied sustainable water management plan of Trichon is lake catchment taking hydrological characteristics and environmental criteria with consideration of rain fall, water demand, water uses, water level fluctuation, groundwater inflow-outflow and evaporation.

Rooijen et al. (2005), analyzed water balance based on water use and wastewater use of Hyderabad city. A large portion of the urban water is potentially reused in wastewater irrigation, though the quality of the wastewater could have important impacts on crop choice, yield, environment and human health. Reuse of wastewater will become increasingly important and complex as cities grow. The water balance of the city of Hyderabad gives insight into long-term trends in the impacts of urban growth on agricultural water use.

Li and Yu (2010) evaluated urban water balance at different levels i.e. house level, property level, district level and urban level which assesses amount of water supply and demand, rainwater and wastewater reusable and the interaction between water supply, wastewater and rainwater.

2.7 Water Sustainability Index

It is difficult to determine water scarcity in physical sense at global scale. Falkenmark et al. (1989) defined 'water stress index' to indicate physical existence of water at national scale. The index separates quantity of water available annually based on estimates of water requirements in the household, agricultural, industrial and energy sectors, and the needs of the environment per person. If the water availability is found below 1700 m^3/person-year, the nation is considered as 'water stress'; if it is below 1000 m^3 /person-year, it is considered as 'water scarce', and if it is below 500 m^3 /person- year, it is considered as 'absolute water scarce'.

Herath et al. (2010) compared Water Scarcity Index (WSI) and Water Poverty Index (WPI). The Water Scarcity Index (WSI) for a country is calculated as the annual water use expressed as a percentage of the available water. In this index, the available water is given by the precipitation falling within the country's borders. Total water use should ideally refer to the sum of 'blue' water (the amount of water withdrawn from ground or surface water) and 'green water' (the amount of water evaporated and transpired from plants that comes from rain water) (Hoekstra and Hung, 2002).WPI is an index of clusters around five sub-indices: resources; access; capacity; use; and environmental aspects. The 'resources' component includes internal water resources and external water inflows. The 'access' sub- index includes the population with access to safe water and sanitation, irrigation water for crops, and water for non-agricultural use. 'Capacity' covers socio-economic aspects which includes income to allow purchase of treated water, plus education and health. The 'use' component accounts for domestic, agricultural and non-agricultural water use. As stated above, the WPI indicator has the advantage of being comprehensive but it is complex to calculate.

Although Falkenmark Index and the Water Scarcity Index are easy to use, but fail to delineate accurately a comprehensive picture of freshwater availability whereas Water Poverty Index covers wider aspects of freshwater availability and use. The utility of indices depend on how well they assess the water demand and supply of a country. In India, the availability of water has been reported to be 1545 m^3/person-year (MOWR, 2012), indicating that the country is under 'water stress' category as per Falkenmark Index.

Frank (2006) discussed the issue of water scarcity from individual to regional scales. Although there is no commonly accepted definition of water scarcity, but when an individual does not have access to safe and affordable water to satisfy one's needs for drinking, washing or livelihoods, we say that person 'water insecure'. When a large number of people in an area are 'water insecure' for a significant period of time, then we can call that area as 'water scarce'. Declaration of 'water scarce' area depends, how people’s need is defined; whether water for ecology has been considered in the definition and what fraction of resource is made available to satisfy those needs. Spatial and temporal scales of availability of water are also considered.

Robert et al. (2011) emphasized on urban growth and fresh water availability according to urban population forecasting for next 40 years. Water shortage is defined as 100 L per person per day, a rough measure of the amount an urban resident needs to live comfortably long-term, including water for drinking, bathing, cleaning, and sanitation including flush toilets. The other findings suggest that water shortage can be alleviated through landscape management and more efficient use of this resource through reuse.

Leeuwen et al. (2012) discussed 24 indicators for “City Blueprint” to assess the sustainability of urban water cycle. To improve urban water cycle, well-developed and equipped urban water supply in different scenarios has been evaluated with respect to all aspects of sustainability. Aspects of sustainability include efficient use of water, energy and non-renewable resources, human and environmental health, public participation, compliance with current and future legislation, transparency, accountability and costs.

Kalbar et al. (2012) discussed a scenario-based multiple-attribute decision-making approach for selection of an appropriate wastewater treatment technology. Seven criteria viz. global warming, eutrophication, life cycle costs, land requirement, manpower requirement for operation, robustness of the system, and sustainability with twelve indicators are considered in the decision making process. However, there is no single index measure for sustainability evaluation.

Castillo et al. (2016) developed a knowledge-based tool for the sustainable selection of wastewater treatment process. An integrated framework for selection of WWTP configuration has been presented to select optimal treatment technology. For optimal selection of WWTP criteria are selected as O &M cost, investment, biogas price, effluent COD, effluent Total N, effluent TP, effluent TSS.

Hence, there is need to implement a system which must include all components of urban water systems which ensures the water supply in all sectors of urban water demand. A single index measure is also required for the reliable assessment of water management and the availability of water for futuristic new developments. An attempt of development of single index measure has been made which is elaborated in chapter 4.