Testing and Evaluation of a Smart Irrigation System towards Smart landscaping in UAE

اختبار وتقييم نظام الري الذكي نحو المناظر الطبيعية الذكية في دولة الإمارات العربية المتحدة

by

FATMA ALSULAIMANI

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Abstract

It is clear that the population is growing drastically causing an increase in urban development and landscape expansion which as a result increase the demand for water. In the GCC region, water is becoming a threat with the impact of climate change and the lack of water resources. The main source of water is mostly desalination plants. Irrigation system can reduce water consumption but the current system might not solve the issues of water in the near future. This study is an evaluation to the impact of an innovative technology, especially the use of Internet of things (IoT) on the performance of a typical irrigation system currently used in Dubai, UAE. A field experiment was conducted to measure the selected parameter: Water consumption and irrigation management. This means, a profound measurement on the impact of integrating soil moisture sensor into the current irrigation system is evaluated to assess the impact this integration. The research evaluates the environmental, economic and technical feasibility of the technology under UAE conditions. The core methodology used in this research was the field experiment; statistical analysis was also required to validate the results obtained on site.

The results observed from the experiment were that the use of smart irrigation system (SIS) have an environmental advantages in the long term especially in terms of water consumption and irrigation management. Less water is required to irrigate when the soil is saturated enough causing a healthier plants growth. The outcomes of the use of SMS have shown a better results in water conservation and a decrease in water flow in the month of September by 21% and 26% in October.

However, the economic analysis shows that the integration of soil moisture sensor isn’t viable in large field projects when heterogeneous soils covers large areas. The upfront cost is higher compared to the controlled irrigation system, yet the long term will have larger impact on the plantation growth and water conservation. Moreover, failing to choose the right depth in which moisture is contained and sensor is buried might cause a negative effect. Nevertheless, integrating new technologies in the irrigation system is a way to move smarter and innovative and this is what Dubai is moving towards.

الخلاصة

إن التسارع في النمو السكاني أدى إلى زيارة ملحوظة في اتساع مساحات المناطق الحضرية وبالتالي الزيادة في الطلب على المياه. ففي منطقة الخليج العربي تعد محطات التحلية هي المصدر الرئيسي للمياه بعد أن أصبحت موارد المياه العذبة مهددة بسبب تغير المناخ.

ترشيد استهلاك المياه في الري ؛ يمكن أن يقلل نظام الري من استهلاك المياه ولكن النظام الحالي قد لا يخدم قضايا المياه في المستقبل. تعد هذه الدراسة تقييماً لتأثير التقنية المبتكرة ، خاصةً استخدام إنترنت الأشياء (IoT) ، على أداء نظام الري التقليدي المستخدم حاليًا في إمارة دبي. لقد قمت بإجراء تجربة ميدانية لقياس الإدارة المختارة: استهلاك المياه وإدارة الري حيث يتم تقييم قياس عميق لتأثير دمج مستشعر رطوبة التربة في نظام الري الحالي لتقييم تأثير هذا التكامل. يقوم البحث بتقييم الجدوى البيئية والاقتصادية والتقنية للتكنولوجيا في ظل الظروف المناخية لدولة الإمارات العربية المتحدة. كانت المنهجية الأساسية المستخدمة في هذا البحث هي التجربة الميدانية؛ و كان التحليل الإحصائي مطلوبًا أيضًا للتحقق من النتائج التي تم الحصول عليها في الموقع.

إن النتائج التي لوحظت من التجربة هي أن استخدام نظام الري الذكي (SIS) له مزايا بيئية على المدى الطويل خاصة فيما يتعلق باستهلاك المياه وإدارة الري. المياه المطلوبة للري تكون أقل عندما تكون التربة مشبعة بما يكفي مما يجعل نمو النباتات أكثر صحة. وقد أظهرت نتائج استخدام الري الذكي نتائج أفضل في الحفاظ على المياه وانخفاض في تدفق المياه في شهر سبتمبر بنسبة 21 ٪ و 26 ٪ في أكتوبر.

ومع ذلك، يظهر التحليل الاقتصادي أن دمج مستشعر رطوبة التربة غير قابل للتطبيق في المشروعات الميدانية الكبيرة عندما تغطي التربة غير المتجانسة مساحات كبيرة. التكلفة الأولية أعلى مقارنة بنظام الري المتحكم فيه ، ومع ذلك فإن المدى الطويل سيكون له تأثير أكبر على نمو المزارع والحفاظ على المياه. علاوة على ذلك ، قد يؤدي الفشل في اختيار العمق الصحيح الذي يتم فيه احتواء الرطوبة ودفن المستشعر إلى إحداث تأثير سلبي. ومع ذلك ، فإن دمج تقنيات جديدة في نظام الري هو وسيلة للتحرك أكثر ذكاءً وابتكارًا ، وهذا ما تتجه إليه إمارة دبي.

Acknowledgment

First, I would like to thank God for allowing me to accomplish this research and my masters despite all the difficulties. Once upon a time it was a dream, and thanks God to my dreams that come true.

I fall short of words to thank every single person who stood next to me. My family, my friends, my colleagues, my professors who took this journey with me, no words can describe how blessed I am.

I also apologize for the time I was busy and away that stole my presence among my beloved family and friends.

Finally, I believed I could, so I did

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Chapter 1 Introduction

Global Review

Humans have always looked into agriculture as the main source of food production. Since the existence of human on earth, they have relied on crops cultivation for food security. With human civilization, they began to examine the aesthetic part of the green spaces by integrating man-made features with the natural resources. These green spaces evolved from agriculture to horticulture including public urban spaces, private gardens and parks, all the way to the street and interchanges. The innovation of green spaces have also offered an opportunity to move vertically by introducing the concepts of green walls, hanging planters, and vertical gardens. Urban green spaces not only used as a source of food production, but also a space where greenery exists for relaxation, meditation, social gathering and a purification buffer from the urban cities.

The increase of population and urbanization have put so much pressure into the need for more agricultural and landscape areas. Yet, as a result of climate change and global warming, water availability is becoming a critical factor impacting the efficiency of agriculture and landscape all over the world. Irrigation practices have gone through a massive development since the urbanization. However, the need for innovative and smart practices can be the ultimate solution.

1.1 Landscape and agricultural revolution in UAE

The landscape and the agriculture of United Arab Emirates is an embodiment of the rapid transformation the tiny desert oasis has gone through in the last few decades. The green pastures delicately and aesthetically balanced in the urban development; preserving and maintaining the mesmerizing symbols of the traditional way of life and culture; and above all traces of flourishing agriculture reflects how far the country tackled the harsh climate and advanced even in the backdrop of relatively low rainfall and compounding water scarcity. The importance of the agricultural sector and its priority to the national development and self-sufficiency of UAE can be better understood by examining the translated words of His Highness Sheikh Zayed Bin Sultan Al Nahyan, the Father of the Nation. “Show me a country that has a strong agricultural base, I show you a strong and established country” ("Pages - Abu Dhabi Agriculture" 2017).

Situated on the eastern side of Arabian Peninsula, the United Arab Emirates shares border with Saudi Arabia and Oman and enjoys a long coastline along the Gulf of Oman and Arabian Gulf. The topography of the country is varied and experiences a very hot and dry climate year round. The geography of UAE can be broadly divided into three zones (Figure 1.1): a low lying, barren coastal region; sand dunes stretching from the coastal plain to the vast desert wasteland; and the mountain ranges sharing the borders of Oman in the north and east. The water scarcity and the harsh desert climatic conditions make the land infertile.

Figure 1.1 UAE geographical map ("livingintheuae" 2017)

This arid region experiences low precipitation rate throughout the year with long hot summers and mid warm winters. The humidity varies from place to place with coastal regions experiencing higher levels. Howari et al. (2007) states that the economy was dependent on fishing in the first half of the 20th century though there were many farming areas namely Diqdagah in Ras Al Khaimah, Falaj Al Mulla in Umm Al Quwain, Wadi Adh Dhayd in Sharjah, Al Awir in Dubai and the coastal region of Fujairah. The massive green spaces existing in the country from time immemorial has been coalesced and developed by Sheikh Zayed with great effort after the formation of the Union in 1971. 'Aflaj', a traditional system for irrigation has been renovated by the founding fathers to reap the benefits and to achieve the full potential of the agriculture in the country and has been extended into remote areas. Serious efforts has been made by the federal government to prevent the desertification of the vulnerable agricultural areas and plots and to protect them for the future use; and many a private contractors were hired to plant and protect the trees, shrubs and plants in the country.

The urban infrastructure has undergone a rapid transformation as a result of the petro dollar prompting the introduction of many advanced technologies in the field of agriculture and the irrigation methods. This has resulted in the renaissance of agriculture and greenery of the country with many millions flowing to the battle of fighting the harsh climate and scarcity of fresh water. As per the 2011 report of the General Secretariat of the Gulf Cooperation Council, the UAE has successfully achieved self-sufficiency in the agriculture for half of the domestic consumption requirements of the people of this country. The domestic production of the fruits can cater to 36% of the needs along with massive production of trees and other plants. The oil and gas industry saw huge capital investment during the last few decades bringing huge current account surplus to the coffers of the country allowing the policy makers deep pockets to support their hand into for the agricultural and the landscape development. The formation of the Ministry of Agriculture and Fisheries had a great impact in boosting and enhancing the production of the agricultural produce and many modernized techniques were adapted to suit the special requirements of the desert climate in the planning and design stages of the primary sector in the country. The local market came with various technologies used in the irrigation system, moving to self-operated technologies and various irrigation systems that depend on plants type and need.

The use of sprinklers, sprayer, drippers and many other technologies have been widely used in private and public sectors to enhance water efficiency and plants growth.

1.2 Barriers of existing methods used in irrigation and the difficulties facing the agriculture and landscaping in UAE

There has been a paradigm shift in agriculture and landscape of the country due to the current irrigation methods and contributed positively to the development of the ongoing boosting of agricultural and landscape activities such as the parks and the gardens. Nevertheless, the population is on the increase mainly because of the higher birth rate among the local population and the continuous inflow of the foreign national in search of better pastures and stress free life not to mention the bad practices of the human beings with respect to the damage to the environment and the precious water sources. Irrational irrigation practices and the water usage is causing tremendous pressure on the water sources coupled with water wastage and increasing energy consumption. Many a streams have gone dry coupled with the Aflaj methods being subjected to drought, and it should be seen in conjunction with the pollution of the ground water and the unbridled use of the ground and surface water including the aquifers. The pace of the urbanization is sure to proceed in UAE with the possibility of many more being added to the urban population in the near future, the better management of the water sources and irrigation is paramount and imperative to sustain the present level of water consumption and to ensure enough water sources for our posterity.

1.2.1 Water scarcity

The economy of the GCC nations has undergone a rapid transformation due to the presence of the oil and gas reserves and the resultant petro dollar. UAE also experienced the better part of the oil boom and wealth resulting in a surge of population in the country from a mere 1.5 million in 1970s to more than 9 million people by the end of the 2014(Qaydi, 2016).

The upsurge in the population has resulted in increased use of the ground and surface water depleting most of the sources not to mention the impacts and adverse effects arising from the desalination plants and pollution of the environment. The present requirement for the potable water and irrigation usage cannot be sustainable with the present or the traditional irrigation systems as there is increased demand for the irrigation towards the agriculture and expansion of green spaces throughout the country.

The geographical location of UAE in the arid and semi-arid region poses severe threat to the natural resources such as the water sources mainly due to the low precipitation rate and the high evaporation of the water. The water used in agriculture is considered the highest in consumption compared to other industries, even though the contribution of the agriculture towards GDP of the country is only a meager 3% in UAE, 1% in Kuwait and 6.5% in Saudi Arabia (Raouf, 2009). Though the current irrigation practices enhanced the productivity in the past, the efficiency of these irrigation practices has been on the wane thereby increasing the water wastage. Furthermore, the irrigation systems such as the flooding and the furrow techniques are inherently not efficient and results in high degree of water wastage and will continue to affect the availability of the water in the country. Moreover, the cultivation of the certain crops requires high water consumption increasing the pressure on the limited water sources.

The abstraction of the large quantity of ground water from some sources has resulted in the reduction of the water table and further deteriorated the quality of the water and it should be viewed in the backdrop of the unregulated agricultural practices and the unscientific water management. The high rate of salinization of the ground water is another major concern for the country caused mainly due to the continuous water pumping and the pollution of the water. Though the introduction of the electric pump supplanted the diesel engines in the 1980s, the quality and productivity of the groundwater has been increasing at the huge expense of the sustainability of aquifers.

The infrequent and comparatively low rate of precipitation coupled with the long term aridity will continue to be constant considering the rise in temperature arising from the global warming. This is further aggravated by the deteriorating green spaces, worsening availability of the water and the increased water contamination. The Fresh water is scare and under increasing threat due to the high demand growth and it will be worsened due the cultivation and the unsustainable water uses and practices. The total distribution of water is divided as more than 98% salty while only two percent is considered as drinkable. Even out of this two percent, the major share consists of snow and ice with only a 30% ground water than can be used for the drinking purposes. The distribution of the water will be further affected by the global warming and the climatic changes in the coming decades as more and more polar ice melt and flow into the sea. Many arid regions in the world will face severe water challenges in the near future with drought and flood wreaking havoc in different regions. The depletion of the ground water is a cause for concern to UAE as a result of the increased use for residential and commercial purposes and it is bound to put more pressure in the years to come due to the rapid increase in the population of the country.

1.2.2 Irrigation Efficiency

The lack of efficiency of the current irrigation practices makes the shift towards a more productive and equitable irrigation system more imperative. Water efficiency is crucial to sustain the sources and this should be properly quantified. The present irrigation systems are unable to cater to this demand and the new irrigation applications will help us to predict the amount of water needed for certain plants during particular period of time and this can bring much needed efficiency to the irrigation system while boosting the utility of the water used. The productivity of the plants and crops are to a certain degree dependent on the amount of water it receives into the soil surface and supplanting the traditional irrigation practices with that of the modern irrigation applications can go a long way in improving the efficiency of the water sources.

1.3 Horticulture and Agriculture in Dubai

To ensure the sustainability of the city and the natural beauty, the Emirate of Dubai is rapidly undergoing enormous changes in the urban planning with more focus on the Urban Green Infrastructure. The parks and the green spaces can inhale the urban contamination while discharging the precious oxygen to the arteries of the city (Anguluri & Narayanan, 2017). This can act as a buffer to the harsh climate while mitigating the risks of the global warming. Furthermore, the trees provide the shade to the pedestrians in addition to enhancing the aesthetics of the city landscape. Aligning with Dubai clean energy strategy, DEWA aims to reduce the carbon footprint considerably by 2050 in order to become of the most sustainable cities in the world (Reporter 2016). Many a strategies have been adopted and implemented in the infrastructure, legislation, funding and environmental sector to achieve the goal by the year of 2050. The Public Park and the Horticulture Department of Dubai Municipality has devised many plans and strategies to decrease the water consumption and improve the landscape practices. The department has cultivated local trees such as Ghaf, Sidr, and Markh so as to reduce the amount of the water irrigated and to beautify the landscape of the city. Replacing the trees of high water consumption with trees of low water consumption, integrating and designing streets and highways with gravels, paving and mulch to reduce the green space are some of the ways to reduce the water consumption and preserve it for future.

The effectiveness of the irrigation, to a certain extent, depends on a complete understanding of the vegetation. Each type of vegetation requires different amount of irrigation of water and at specific intervals for the proper growth and this is integral to the smart and sustainable landscaping of the future. Palm trees, ornamental trees, shrubs and seasonal flower are cultivated in Dubai Emirate for the aesthetics and horticulture. Table 1.1 summarizes the different water requirement for the varied plants as per the Dubai Municipality standard for the effective irrigation on a daily basis.

Table 1.1 Vegetation type, water requirement and irrigation system used for each type **(**Ziauddin 2017)

Plantation type	**Water requirement**	**Irrigation system used**	**Max daily operation timing for irrigation system**
Palm trees	100-150 Lit/day	Bubbler	30 Minutes
Ornamental trees	100-120 Lit/day	Drip irrigation	2 hours
Fruits	-	Drip Irrigation	-
Grass	15 Lit/m^2/ day	Sprinkler/ Sprays	Between 20 min – 3 hrs

			depending on type of sprays and sprinkler
Shrubs / Hedges	25 Lit/day	Drip irrigation	2 hours
Ground Cover, Flowers, creepers	15 lit/ day	Drip irrigation	2 hours

The true vision of Dubai will be realized only when there are more green spaces. Thus there is an urgent need to bring alternative methods to boost the efficiency in the irrigation practices of horticulture and agriculture in the emirate. Technology can play a large role in this next generation of irrigation systems for the proper integration practices and to reduce the negative impact of the unscientific management of the irrigation practices.

1.4 The smart city revolution and the need for smart technologies in landscaping and agriculture sector

The digital revolution and the latest disruptive technological innovations offers hope for the humanity in terms of improving the efficiency in all spheres of life and irrigation is not an exception to this rule. Increased urbanization is the feature of the modern world and as per a study by the United Nations 75% of the people will be living in the cities by 2050 (United Nation cited in Bibri & Krogsties, 2017). The rapid urbanization can put further pressure on the finite resources especially in the energy sector in addition to contributing abnormally for the already delicate situation of global warming and climate change. Increased water and air pollution, traffic congestion and the disposal of large scale toxic waste are some of the threats waiting to happen. To prevent this from happening, a conscious effort should be made towards the use and appropriation of the natural resources. The introduction of the concept of smart cities globally is a welcome step towards this end and it encompasses large scale use and integration of the Information Communication Technology (ICT) and the Internet of Things (IoT). The smart technology can improve the efficiency and help in reducing the wastage of resources such as the water and energy coupled with a marked enhancement of the quality of the life of the people of this planet. The long term planning and development and the intelligent operational and functional services will help the planners to scale up operations and bring much needed efficiency to the use of the resources. Innovative solutions and smart technologies is not a panacea for the finite resources but if managed and used properly, it will help us to conserve and protect the limited resources for the future as well.

1.4.1 Internet of Things

The Internet of things (IoT) is the buzz word in all the spheres and they denote the connection of various gadgets, buildings, and vehicles with the help of the software, sensors and the electronic networks to better coordinate and exchange data and information as and when that occurs and the term 'internet of things' was first coined by Kevin Ashton in 1999(Ashton, 2009 cited in Garcia-de-Prado, Ortiz & Boubeta-Puig 2017). The idea is that the IoT can radically transform this technologically and digitally advanced world into a powerful human connection that eventually leads to an increase in people's happiness. A report from Mckinsey Institute anticipate a large economic growth of 11 trillion $ in the upcoming 10 years from the use of IoT. Moreover, another collaborative study by Smart Dubai and CISCO in the year of 2014 revealed 17.2 Billion Dirham's value for both sectors, public and private by 2020 (Reserved. 2017). The idea goes beyond the mere connection of the devices rather the sheer size of the amount of data and information that will be generated and transferred online, the impact of IoT will profoundly be seen in the enhancement of the quality of people's life and the sustainable aspect.

Sensors, actuators and controllers will be used through IoT for the management of the devices and it will be accessed by way of the latest mobile or computer based systems from anywhere. All the web enabled devices can collect send and act on the data that they receive from their surroundings with the help of the embedded sensors and processors. These devices can talk to each other in a process known as machine to machine communication. These gadgets can be used and managed for their requirement by the humans though the devices act on their own for the better part making the continuous interaction by the humans redundant.

Figure 1.2 provides the basic architecture of the Internet of things and it consists of the smart devices, network infrastructure and the above all the servers needed to back up the data. IoT is already used widely in many sectors such as the financials, media, security, healthcare, energy and infrastructure recently for the effective enhancement of the productivity and to achieve cost efficiency.

The Dubai government has been keen and eager to integrate the Internet of things in many of their activities and services with many buildings, services, business and objects in the city being integrated in the smart system. The use of the sensors, actuators and other innovative technologies become part and parcel of our daily life wittingly or unwittingly and will continue to play a major role in the days ahead. How this internet of things can bring efficiency and better management of the irrigation system to protect and conserve our environment and scarce resources is a serious matter with long term impact on the agricult8ure and landscape of this beautiful city called, Dubai.

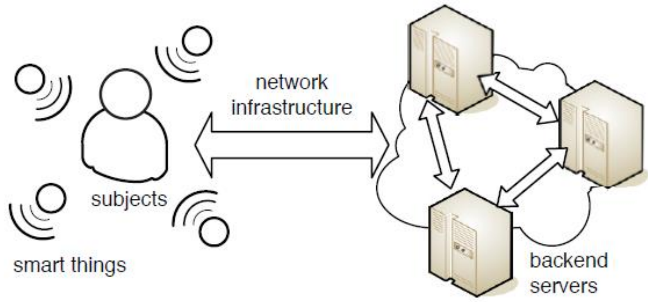

Figure 1.2 Simple component of the architecture of IoT (Lopez et al. 2017)

1.5 Research Plan

This dissertation discuss the integration of smart irrigation practices using soil moisture sensor and its impact on water saving. Thus, the study elucidates how water scarcity in the region can be tackled with the use of smart technologies. In order to understand the concerned water problem in the region, the global impact of water scarcity and its effect on climate change, and the irrigation technologies; a comprehensive literature review is conducted. Second, various methodologies used in the subject area have been profoundly studied and then the most suitable method has been chosen for this dissertation according to the time boundary and available resources.

1.5.1 Aims and objectives

UAE has shown a great boost in agriculture and green spaces and water consumption is in continues demand. The need for an innovative irrigation applications are necessary to compete with the requirements. The conventional irrigation practices used have shown a productive approach in enhancing the cultivation of the region, yet with the challenges emerging that is related to population growth, water shortages and climate change, the efficiency of these practice are in dilemma. It is found from the practices used in UAE that large amount of water is consumed by using the traditional system. Moreover, in many practices the water gets evaporated before allowing the plant to absorb due to the harsh climate condition of the region. Therefore, large area of planted vegetation is highly affected by the irrigational irrigation system and more water is consumed to compensate the deficiency.

The smart solutions arise in agriculture and landscape was a result of the vital need to compensate the short supply of water in UAE and provide a systematic approach to avoid future challenges. As Dubai is going through a tremendous transformation towards smart city, many sectors have been integrating smart paradigms in their infrastructure, transportation, energy and environment. As sustainable agriculture and landscape plays a critical role in enhancing the environment, this research will profoundly investigate the potential of integrating smart irrigation methods for the hot arid environment of Dubai, UAE.

The aim of this study is to assess the current irrigation system used in Warsan Nursery in Dubai and measure the water efficiency of its irrigation systems (Sprayer and Dripper). The studied systems that will later be elaborated in the next chapter are smart systems that have been used internationally and some were also been used locally by various private investors. Other systems were explained to show the evolution of irrigation system especially in the GCC region. Within this context, the study is also aiming to investigate the role of smart irrigation practices in enhancing water efficiency on various types of vegetation.

Following are the objectives of the research study:

- Studying the existing irrigation systems used in Dubai by looking into various case studies that measure the impact of the current practices.
- Exploring the prevailing irrigation technologies available in the market and suitable for the region that will enhance irrigation water usage.

- Identifying the different parameters affecting the usage of conventional irrigation system in Dubai.
- Integrating irrigation smart features in the landscape and agriculture of Dubai
- Reviewing the performance of smart system through field experiment
- Enhancing the sustainability of the landscaping in the region.

1.5.2 Expected outcomes

The study is intended to get a coherent understanding on how smart technologies can be utilized in the field of smart landscaping and agriculture. As water is one of the biggest concerns in the region and very essential for the prospective evolution, it is important to seek for various alternatives in irrigation practices; smart and sustainable alternatives that leads to efficient water consumption. Following are the study's expected outcomes:

- A broad overview on the main issues facing the landscape and agriculture in the region
- Extensive understanding of the irrigation practices used in various countries, especially the hot arid and semi-arid regions.
- Profound understanding on the various irrigation technologies available in the UAE market and can be used to tackle the current issues found.
- The impact of smart irrigation technologies, especially the ones integrating Internet of things in enhancing water conservation in Dubai's landscape and agriculture.

Chapter 2 Literature Review

This chapter looks into various examples in the challenges facing hot arid region and the current practices used in these regions. The challenges have been interpreted in various aspects of sustainability to measure the environmental impact. Then it looks into the irrigation practices used in regions with similar environmental and climate conditions. Moreover, it also elucidates the smart technologies used in agriculture and landscape sector that are available in the market and used in different parts of the world.

2.1 Water challenges in semi-arid and arid regions

2.1.1 South Asia

The use of groundwater has increased exponentially with the economical increase in many countries in south Asia. Steenburgen et al (2015) elucidates the decrease in Pakistan’s water table due to irrational use of groundwater which is causing a threat to the agriculture’s sustainability. The basin in Kuchlagh in Pishin Lora Basin in Pakistan has faced a significant decrease in the past 30 years. With the economic boost in 1980 that was due to the expansion of the transportation rout to large markets in Lahore and Karachi along with the influx of Afghanis to the area. Kuchlagh is an example of many areas in the semi-arid region that are highly dependent on groundwater, yet, the unmanaged practices are causing a massive deterioration in water table.

John (2011) states that the demand for water has increased dramatically in South Asia to serve various purposes in agriculture, drinking, and other industries. On the other hand ,the past half century has witnessed a massive reduction in the availability of water due to the intensive farming, unmanaged water pumping from groundwater, water contamination and pollution, and the lack of policies that serve water consumption.

According to a study by (Srinivasan et al. 2017), India is one of most water stressed country in the world and more than 54% of the area are affected. The country is highly dependent on groundwater causing a high depletion on water table. With the continuous development, the demand for water has also been increasing, especially in agriculture, electricity and household purposes. Climate change has also contributed on deteriorating the availability of water in the region by changing and altering the raining season along with the changing run off locations and its quantity. In a study conducted by (Prabhu 2017) Figure 2.1 shows the categorization of water indicating that large amount of water in India are under the threat of overexploitation. On the other hand, some states such as Gujarat were able to increase the level of groundwater by introducing the technique of storing water in check dams.

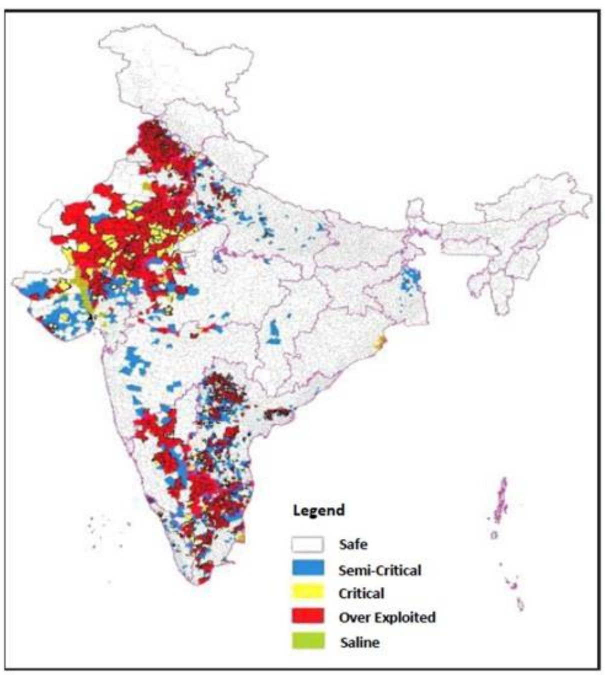

Figure 2.1 Water categorization in India. (Prabhu 2017)

2.1.2 United States

Water supply and demand has also been a crucial topic in some of the hot arid States in America, especially with the increase of water supply and water demand. According to a study conducted by Scanlon et al. (2012) 90% of global freshwater was consumed in irrigation, 20% used in crops and 40% in food production. Most of the irrigation water used in the past centuries is pumped from groundwater sources making it one of the important water sources. 40% of lands globally are irrigated using groundwater, while 60% within the United States. This has caused a massive deterioration to the aquifers of the States due to overexploitation. Reference to the previous study, it has also showed an increase in the global groundwater depletion between the year 1960 and 2000 in various spots especially the high plain and central valley in California. Since 1900, the area has been facing a great groundwater exhaustion impacting the agriculture of the area. Faunt (2009) states that 20,000 square miles of the Central valley is covered with a productive agriculture and one of the most prolific land in the world with more than 250 various crops. These planted crops are highly dependent on surface and groundwater. Faunt also mentioned that one sixth of world's irrigated land is located in the Central valley, and one-fifth of the world's groundwater demand is provided from its aquifers. With the increase in population and urban planning, the demand for water recourses has doubled putting too much pressure on Colorado River water. As a result to the high demand of water, various issues were found in the area effecting agriculture land and climate variability.

2.1.3 Gulf Cooperation Council (GCC)

The depletion of the ground and surface water presents an existential challenge to the policy makers in the Gulf Cooperation Council (GCC). The other major challenges facing the GCC nations include desertification, loss of local biodiversity and the destruction of the ecology, pollution of the marine and coastal region and above all water scarcity and quality. The population increase arising out of comparatively high birth rate in the region and huge inflow of expatriate community has added to this water challenge and resulted in the shrinking up of many conventional water sources like surface water, ground water and the shallow and deep aquifers. The non-conventional sources of water from desalination plants and the wastewater recycling, although eased off the pressure from the conventional sources, is presenting many other unforeseen challenges as it comes with certain caveats. The prospect of further desertification, loss of bio diversity, marine and the coastal pollution, and above all water scarcity and the quality will exacerbate the ongoing situation and make it intractable for the governments as well as the individuals (Raouf, 2009).

The low annual precipitation rate in the GCC countries results in water shortage when ground water and surface water is abstracted unsustainably. Rapid urbanization and the wasteful consumption pattern of the domestic and the agricultural sector exacerbate the water situation in the GCC and the technical and the economic difficulty of importing water from water rich foreign sources such as Iran, Egypt, Pakistan and Turkey make the proposal redundant. Rashed and Sherif (2000) state that the lack of renewable water resources is the critical issue facing the GCC nations coupled with overexploitation of the fossil ground water resources. They are of the view that the low oil price along with the increasing cost of the desalination plant makes it economically not feasible. Adopting highly efficient and sustainable integrated water policies;

and the implementation of advanced technology to maintain and conserve the water resources. In addition to recycling of the water, treatment of the waste water and the artificial recharge of the ground water by way of the surface water can see the GCC through this crisis (Al Rahsed, 2000).

The World Bank data reveals that more than half of the people in the Middle Eastern region live under the water stress conditions meaning water demand far outstrips the supply and availability of the water. The per capita availability of the water is expected to halve by year 2050 mainly due to the increase in the population and the water scarcity may present another difficulty to the budget by way of increased cost of arranging the fresh water (Arozamena, 2017). Seventy percent of the desalination capacity is found in the Middle East and by 2020, Saudi Arabia has earmarked $24.3 billion towards desalination plant expansion. UAE has embarked on a mission to reduce the carbon footprint of the desalinated water by launching Global Clean Water Desalination Alliance (GCWDA) and the strategy is to increasingly use renewable energy for the energy needs of the desalination plants instead of fossil fuel (Arozamena, 2017).

Dr Han Sueng-Soo is of the opinion that UAE is very vulnerable to the climate change and faces many challenges to the sustainability of its environment and ecology. The former prime minister of Korea and UN’s special envoy further argued that water consumption in UAE exceeds 24 times the natural recharge capacity of the ground water and has decreased by 18 percent since 2003 (Malek, 2015). The Arab Human Development Report 2009 reveals water scarcity as the greatest and gravest threat to the human security in the Arab world (Mahmoud, 2016). Mahmoud argues that high population due to the high birth rate of indigenous Arabs as well as the increasing inflow of guest workers led to the explosive use of the water. The total population of 8 million in 1970 in the Gulf States has gone up to 45 million by 2010 resulting in the sharp drop in the per capita water availability of fresh water from 600 cubic meters per year to 160 cubic meters per year over the same period (Mahmoud, 2016).

To ensure the sustainability of the water sources, the regional states have been adopting a variety polices for the proper water management. Water controlling is the catch word as GCC nations vie against the nature to secure their future demand for the water. The elimination of the over drafting of water for the agricultural purposes both from the renewable sources and the non-renewable sources has to be seen in this context. Pirani and Arafat (2016) warn that the pace of the water demand will increase as the population increases in the GCC nations as the need for the food security will be greater. Figure 2.2 reveal the low rate of the use of the renewable sources of water in the GCC nations compared to the nonrenewable sources of water. Oman is the only state with high percentage of renewable water sources while the other countries in the union are highly dependent on the nonrenewable water sources such as desalination plants and treated waste water for their water use.

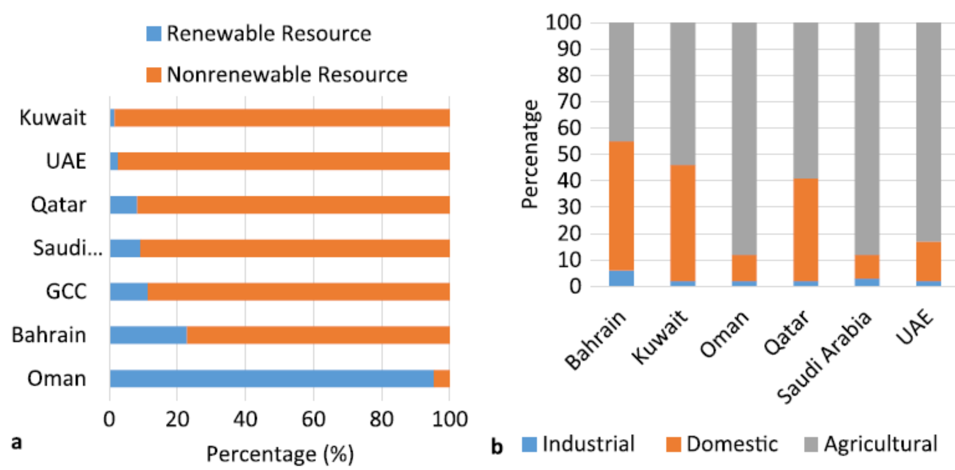

Figure 2.2 Renewable and nonrenewable resources of water consumption in GCC Countries (2013) (Sayed and Ayoub, 2014 Cited in Pirani & Arafat 2016)

2.1.3.1 Limited availability of water resources in GCC

The lack of fresh water lakes in the GCC makes it solely dependent on the rainfall for recharging the ground water and the surface water that is fast being depleted for domestic and commercial use. The annual rainfall in most of the GCC countries are averaged between 70 and 140 mm per year in the region not to mention the high evaporation rate and the hydrological impact of the climate change (Al-Rashed & m. Sherif 2000). Most of the surface water are available at the East side of Oman Mountains and Southwest of Saudi Arabia. The average rainfall is approximately higher in these two locations and can reach up to 500 mm per year causing runoff. The runoff caused at the western mountains of Oman benefits the area of UAE and Oman.

The shallow renewable aquifers have limited replenishment rate exacerbating the use of the nonrenewable supplies of large deep aquifers. The desalination plant that got accelerated growth after the oil boom in Gulf region comes with many caveats and the reclaimed wastewater is not used extensively accounting for only twelve percent of the domestic water supply mainly for the irrigation of the urban garden and city landscapes. More than 57 percent of the global desalination of the water happens in the Gulf region water with more than 30 desalination plants in Saudi Arabia alone. The waste water treatment has not been fully tapped in the region and is still used for irrigating the gardens and parks in the urban centers along with irrigating the highway landscape and the fodder crops (Mahmoud, 2016).

The ground water is fast depleted in Gulf region due to over extraction or at a rate greater than the replenishment of the ground water through natural means. Degradation along with high extraction rate is as a result of the fast sea water intrusion into the aquifers is presenting immense challenges to the Gulf region as far as the ground and surface water is concerned. The unsustainable cultivation of food grains using the precious ground water is also a reason for the depletion of the aquifers. The recent example of Saudi Arabia having to abandon its effort to achieve food self-sufficiency is an excellent example of how the scare water resources has been utilized unsustainably for a long period endangering the water sources.   The surface and ground water quality is greatly affected by the agricultural, industrial and the municipal wastewater in the region. The greater Stalinization of the water sources and the over pumping is another reason for the depletion and the degradation of the water sources such as the ground water and the surface water in the region (Frenken, 2008).

2.2 Environmental Sustainability

The environmental concerns arising out of the large scale desalination plants as a result of the extraction of the salt from the sea water cannot be neglected. Heating seawater and condensing steam or the reverse osmosis in which the water is pushed through a membrane in order to filter out the salt, causes various environmental damages. The input concerns such as the large scale intake of the sea water can cause the destruction of the marine ecosystem in the region by destroying the local marine life and environment. The output concerns can arise from the oil spills and red tides as far as the Middle Eastern sea or marine water is concerned. The greenhouse gas emission arising out of the fossil use can further aggravate the situation in the gulf region by climate change bringing with it varied problems like drought, famine and flood on a random basis.

2.2.1 Energy and Water

There is a water-energy –food nexus in the gulf region meaning water challenges are worsened as a result of this compounding of the multiple nexuses. Energy is an important part of the value chain of the water as the abstraction of the water is energy dependent not to mention the purification of the water using the high energy intensive means (Mahmoud, 2016). In addition to that the transportation to the urban areas is also another energy consuming process. This interlinks between the water and energy is on the rise in the Gulf region bring production and consumption of energy and water at a crucial juncture. The proper water management and governance is necessary to support water security and to facilitate the transition into the green economy. If there are energy efficient means and renewable energy sources for the extraction of the water and transportation, the environmental degradation can be prevented and sustainability can be achieved.

2.3 Water conflicts

The water shortage and scarcity may lead to conflicts in the region endangering the fragile situation of already highly polarized society. The black farmers and the Arab nomads in the Darfur region of Sudan is a stark reminder of this inflammable situation in the MENA region as they engaged in numerous conflicts for the scarce water sources. Reaching a consensus for the fast depleting water sources use will be challenging for the modern nation states if there is no prior accord, policies and conventions to tackle it in the future. Water is the most important basic rights of the people and depriving it to the people even if other nationals is tantamount to denying the right to live. We cannot deny the possibly of water being used as political tool in the MENA region in the years to come (Raouf, 2009).

2.4 Irrigation practices in the semi-arid and arid regions

Countries in semi-arid and arid region share similar climatic condition in which the type of irrigation systems used are almost the same depending on water requirement of each plant. El Wahed et al. (2015) states after conducting a study on the effect of sprinkler irrigation system design on the barley crop yield production (CWP) on Sebha environmental conditions in Libya that surface irrigation, sprinkler irrigation and the drip irrigation are the preferred method as water becomes scarce in this region. The authors recommend using the solid set sprinkler irrigation system on Barley production and to obtain highest coefficient of uniformity and distribution uniformity which in turn will reflect on the grain yield (El-Wahed, 2015). Lack of even distribution of water and less amount of water for the plants is detrimental to the plant and will bring fewer yields as a result of the sprinkler irrigation method.

Drip irrigation is another method used as an alternative to the sprinkler irrigation in the arid and semi-arid regions. Perforated tubes will be placed or buried near the root of the plants allowing it to deposit water directly to the plant roots. This can bring down the evaporation of water loss to a higher degree. The drip irrigation in the arid regions has found to have significant impact on the water saving and conservation in addition to boosting the yield of crops and farm productivity and profitability. Another advantage of drip irrigation is that of cost efficiency (D. Suresh Kumar, 2010). Kumar & Palanisami (2011) argue for a shift in the irrigation policy with emphasis on the drip irrigation on those regions with scarcity of water and labor to boost the production of crops in wider space after conducting a study on the arid regions of Southern India. Fentabil et al. (2016) argues that the Micro-irrigation such as the Drip irrigation is helpful in conserving the water by matching the water supply in accordance with the demand of the plant demand. A study conducted on the apple orchards for a two year cycle has revealed that drip irrigation and the frequency management of the water used on the apple orchards can considerably reduce the water consumption (Mesfin M. Fentabil, 2016). Acar e. al (2014) states that use of the drip irrigation in the semi-arid climatic region of Konya closed Basin of Turkey affected the water availability in the region and the sustainability of the agriculture. The drip irrigation had a severe impact on the water resources as the demand for water increased in conjunction with more cultivated land.

Furrow irrigation, basin irrigation and border irrigation schemes are three other irrigation practices used in the arid and dry region of Iran especially in the Jaizan Plain. Albaji et al. (2015) states that though the farmers had been reliant on the surface irrigation practices in times of winter and summer, the drainage restricted the use of the surface irrigation method. The authors are of the opinion that drip irrigation will have a significant impact on the land productivity and water conservation compared to the sprinkler or surface water irrigation as the soil characteristics and the topography favor it in addition to least negative impact on the environment. The furrow irrigation, basin irrigation and the border irrigation schemes are not water efficient and not sustainable as more and more water sources especially the ground and surface water sources disappears due to the climatic change and global warming.

The depletion of the ground water is a specter that is impending on living beings and it was exacerbated by the irrigation for increasing the food production of burgeoning population. Steenbergen et al (2015) argues that the scarcity of resources such as the water can be overcome by the technological innovation, cooperation and conservation, proper regulation, market mechanism, pricing and above all efficiency in consumption. Kuchlagh regin of Balochistan is an excellent example of how the ground water is depleted due to the overuse and lack of oversight and efficiency in use (Frank Van Steenbergen, 2015). In order to save the ground water and to maximize the use of the rain water Tank irrigation has been widely used in the semi-arid and arid regions globally. There are two kinds of tanks namely the System Tanks and Non-System Tanks. If the Tanks are fed by the canals it is known as the System Tanks and if Tanks are fed by the rains it is known as the Non-System Tanks and will have usually small capacity compared to the Non-system Tanks.

Tank irrigation investment is comparatively less capital intensive making it one of the economical irrigation methods in addition to having least effect on the environment. The tank irrigation can reduce poverty in rural areas by improving the productivity or yield in agriculture (Sebak Kumar Jana, 2012). The authors' study has revealed that the tank irrigation can boost the cultivation when there is diversification of crop in the dry zones by enhancing the water availability at all times bringing more productivity in agriculture. Reddy (2015) argues that a holistic approach is needed to bring optimum result from the tank irrigation after studying the tank irrigation in vogue in the southern states of India and Sri Lanka. The ground water exploitation in India got reprieve as more tank irrigation method was chosen to collect and store the precious rain water during the rainy season (Reddy, 2015). Oppen and Rao (1987) conducted widespread examination of the tank irrigation in the Indian states of Andhra Pradesh and Maharashtra so as to find out the economic advantages. There are mainly three irrigation systems prevailing in Indian dry zones with major, medium and minor irrigation systems. The Major Irrigation systems irrigate the large areas and are built on the banks of the perennial rivers as large dams and canals. The medium irrigation systems are built by way of the large tanks or run-off water and finally the minor irrigation systems consists of the ground water and the surface water sources. The tank irrigation is used for two purposes namely for the drinking water as well as the irrigation of the agriculture as the plentiful of the rainwater from monsoon helps feed the tanks thereby helping conserve the ground water and the environment (Rao, 1987).

2.4.1 The development of irrigation system in UAE

A cursory glance at Dubai suburbs reveals many puddles of water on the sides of streets and sidewalks forcing one to ask can Dubai or the Gulf region in general affords or spare this kind of wastage of water? Water is in short supply and the irrigation practices can be attributed as the culprit partially for this huge paucity of water. According to an article published in Khaleej Times newspaper “The UAE is among countries with the highest per capita water consumption in the world”. The author of the article, Reporter, also states that nearly half of the Middle Eastern countries will face water stress by 2040. The UAE and the GCC countries are falling in the top ten countries that will face extreme water stress in the 25 coming years (Reporter 2015).

A glimpse into the traditional irrigation system will help us to better understand the need for the modernized applications and their use in the context of the specific requirements in the agriculture and landscape of UAE.

Primitive tools and equipment designed and crafted by hand, though rare and scarce, has been prevalent for a long period and has been used in conjunction with animal’s power. The major tools used by the agricultural community in the Emirate includes Ox-drawn Plow, Meshah (harrow), Mahhash (trowel) for the tilling the soil, das and miyaz (sickles), the minsharah(saw), khaseen (axe), methrab (wood stick) and ittelah (iron rod) for digging the holes on ground. There were mainly four water sources in the country namely springs, rainfall, wells and the Aflaj. Underground water sources and aquifers were used to pump water for irrigation purposes.’

Falaj', the plural of 'Aflaj', is one of the oldest man made irrigation system widely used in the Gulf region and is dependent on the gravity (Figure 2.3).

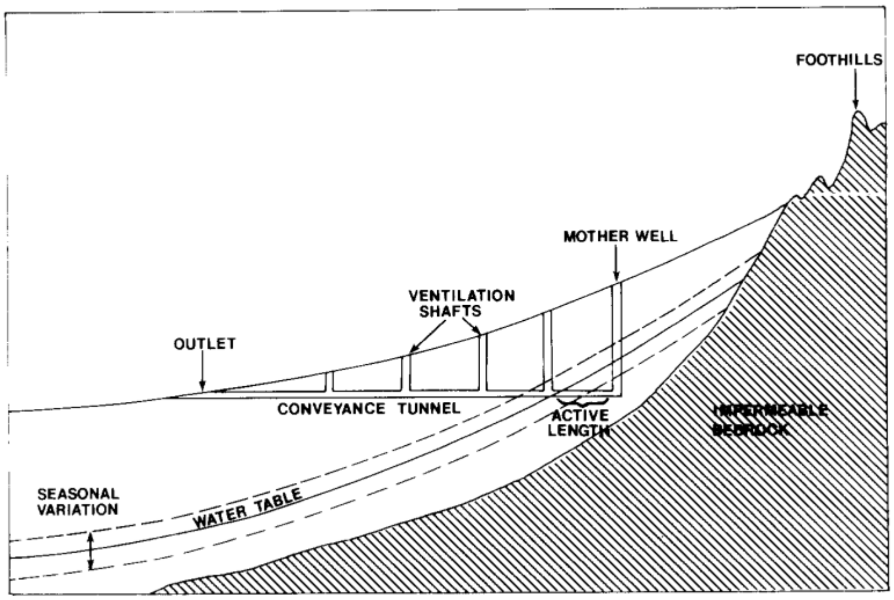

Figure 2.3schematic representation of Aflaj (Parks and Smith, 1983)

Using the underground canal the water will be allowed to flow from the higher elevation gently to the lower arable land as per the demand after storing the water from the surface and spring water above ground.

There were two major type of Aflaj prevalent in the region with one continuously allowing the water to flow year round and the second Shallow Water Afla j wherein water will be available only on rainy days. Aflaj was used widely to control the flow of the water to oasis where it fed the green pastures and other plants. Though the Aflaj were used for the drinking water purposes as well as the irrigation, it has been limited to the irrigation purposes only that too in certain areas of the country recently mainly due to other modern means of the availability of the potable water. Some researchers trace the origin of the Aflaj to the Bronze Age while majority is of the opinion that Aflaj was first developed during the Golden Age of Islamic period. Environment Agency of Abu Dhabi (2006) reports that, the combined discharge of all ‘Aflaj’ irrigation system has declined from 160,000 m^3/year in 1964 to 100,000 m^3/year in 1993.

Drawing water from the wells was major water sourcing for the people of this country especially the farmers. The term “Al-yazerah” referred to teaming of the oxen and/or donkey to draw the pail of water up from the well as shown in Figure 2.4.

Figure 2.4 Al – yazerah (Saif n.d.)

Moreover, ‘Al- mansefah’ or ‘Shadoof’ was also a popular traditional irrigation technique widely used thorough out the region meaning drawing water manually from the well. Different types of loads, levers and lifts were used to lift the water to the surface area by the farmers and general public alike for different irrigation needs. The availability of the water was not an issue in the past in this part of the region due to the very limited inhabitants and the low demand for the irrigation use. Agriculture was not main means of livelihood for the erstwhile Emiratis as most of them were dependent on fishing and rearing of animals. This has helped the people to conserve the precious water sources by consuming judiciously as agriculture and farming would have forced them to use the water sources indiscriminately resulting in serious scarcity of the drinking water.

The current irrigation system prevalent in the country came into existence after the discovery of the oil and the inflow of the surplus petro dollars and is consistent with the modern technological development in the field of irrigation elsewhere globally. The large influx of the immigrants to cater to the rapid transformation of the economy that the country witnessed and the increasing birth rate among the local population has, no doubt, increased the pressure on the water sources that was traditionally available. To keep pace with the growing demands and the increasing use of the water, the policy makers has introduced more efficient irrigation system throughout the country. Even though the climatic conditions are adverse and the water sources are scarce, the authorities has been successful in implementing and executing a variety of modern irrigation techniques and systems and ensured safe potable water to the residents around the year without interruption and not to mention taking care of the agricultural and aesthetic needs that the country witnessed in the last few decades. The new irrigation technologies adopted by the government have helped the transition from desert into a green paradise with many more water preservation and conservation policies encompassing major wells, springs and aquifers in the country. Moreover, the UAE has been looking for many alternatives in water solutions in irrigation and freshwater. The use of desalinated water is one of the alternatives that has been adopted by the government of UAE. Many of these plants are operated by solar power to promote the use of renewable energy and environmentally friendly technologies. These plants are economically feasible and reduce the emission of Carbon dioxide.

The water preservation and conservation has been given more emphasis and proper awareness for the use of the water has been conducted often among the farming community and the general public. As a result, the total area under water management has gone up from 66,682 hectares in 1994 to 226,600 in 2003. The modern irrigation methods included the use of the sprinklers, drippers, bubblers and tanks to effectively and efficiently use and preserve the water for the optimum result. The total area under water management by way of various irrigation technologies in the country is given below with the help of Table 2.1:

Table 2.1 Areas in UAE that have been adopting modern irrigation system (Irrigation in the Middle East region in figures, 2008)

Region/Zone	N° of farms	Area				
		Drip	Bubbler	Sprinkler	Other	Total
Abu Dhabi	20 227	145 335	19 939	18 046	3 499	186 818
Central	2 015	1 444	2 231	1 424	821	5 919
Northern	842	1 651	1 110	1 724	1 061	5 546
Eastern	337	197	774	160	0	1 131
Total	**23 421**	**148 627**	**24 053**	**21 354**	**5 380**	**199 414**

2.4.1.1 Sprinkler irrigation system:

Sprinkler helps in equitable distribution of the water in the irrigation process of various green spaces, and is widely used in the sandy areas as it can help identify the wastage of water arising out of seepage and evaporation. Water is distributed through the pipes by way of pumping and the sprinkler will spray the water into the air as shown in Figure 1.1 and it breaks up into small drops as they fall into the ground below.

Figure 2.5 Sprinkler irrigation system (Sprinkler maintenance & Irrigation services in Dallas, TX - 1-800-Lawn Care 2017)

The sprinkler, pump supply system and the operating conditions are the three main components that help in the uniform distribution and the application of the water. The sprinkler system of irrigation is widely used in the industrial and residential projects of the country and the 'Sprays' denote the fixed pattern of sprinklers that operate in low pressure environment. The 'impact sprinklers', a higher pressure sprinkler variety, moving in circle motion due to the force of the water is also widely seen in the country. The 'RainGun' irrigation system is another sprinkler system that operates under very high pressure in addition to the 'impact sprinklers'. Sprinkler systems vary with respect to the size of the irrigated land with many varieties such as the permanent, portable, semi-portable etc and can either operate automatically or semi-automatically. The major difference between the portable sprinkler irrigation unit and the semi-portable sprinkler is the use of the fixed pumping unit while those of the permanent sprinklers will always be located at a fixed place. The sprinkler irrigation system was first used in UAE on 1983 as a pilot project in a farm and proved to have saved sixty percent of the water used compared to the localized irrigation means (Irrigation in the Middle East region in figures, 2008).

2.4.1.2 Drip irrigation system:

Drip irrigation shown in Figure 2.6 is another modern irrigation method widely used in the Emirate of Dubai and the surrounding regions with similar climatic conditions. This type of irrigation practice can efficiently use the limited water sources for maximum use.

Surendran, Jayakuman and Marimuthu (2016) argue that efficiency of drip irrigation is 70-90% higher compared to the traditional irrigation practices mainly due to the minimization of the surface runoff and avoidance of loss of water due to the percolation.

Figure 2.6 Drip irrigation system ("Learn about drip irrigation - Irrigation Australia Limited" 2017)

The drip irrigation is also known as the 'Trickle Irrigation' or 'Micro Irrigation' as it saves water by allowing dripping gradually to the roots of the grass or plants or the soil by way of the valves network, emitters and the narrow tubes. Perforated pipes are placed closer to the roots allowing the water to flow smoothly to the roots of the grass or the plants.

The hot and humid climatic conditions of Dubai and other emirates results in more than 60% of the water being gradually evaporated before it reaches the grass or the plants that is intended to be irrigated. The water being lost before it is being absorbed or infiltrated is a huge cause of concern for countries like UAE with scarce and limited water sources. Drip irrigation has helped to save the precious water sources considerably whether it is for the agriculture or landscape requirements. Drip irrigation can considerably reduce the water use arising out of the evaporation and can also bring down the loss of nutrients and fertilizers by way of the water leachate. The drip irrigation does not require the field leveling and involves less labor for the operating and maintenance of the system. Compared to the sprinkler irrigation system, the drip irrigation uses only 25% of water and is very economical during the period of drought and low precipitation. Madhavachandran and Surendran (2016) argue that the drip irrigation can improve the profitability of the farmers in areas of water scarcity.

2.4.1.3 Tank irrigation system:

Tank irrigation is another major irrigation systems widely used in UAE by collecting the water in concrete storage and being pumped from the underground to the irrigated area in accordance with the demands and requirements of the trees and plants (Figure 2.7). This can be operated by two means namely the flooding of the furrow or by transferring the water from the tank through concrete lined canals.

Figure 2.7 Tank irrigation system **(**"Rural R22700 Tank Package | The Water Tank Factory" 2017)

Jana, Palanisami and Das (2012) define the tanks as a small scale surface reservoir storing water mainly from the rainfall run-off. The major advantage of tank irrigation is the saving of the water occurring due to the penetration into the ground, in addition to being the economical irrigation means compared to the sprinkler and drip irrigation and being more effective in times of rainy season to save the rainy water. But on the other hand, this tank irrigation can result in the loss of water due to the evaporation especially in the hot and harsh climatic conditions. The Tank Irrigation requires large space to locate the tanks distorting the public appearance. Moreover, large quantities of sediments are carried to the tanks as rainfall occurs along with the water into the tanks necessitating continuous de-silting of the water thereby increasing the cost of the operation. This type of irrigation is used at night to avoid the evaporation loss by some farmers and in the words of Jana, Palanisami & Das (2012) tank irrigation plays a significant role in the sustainable irrigation development of dry zones.

2.4.1.4 Bubbler irrigation system:

Bubblers are used for the irrigation purposes in UAE most notably for the irrigation of the trees especially the fruit trees such as the mangoes (Figure 2.8). The average water consumption of this method is around 19,000 cubic meter/2.47 acres annually (Saif n.d.). Bubbler irrigation system employs water on the soil surface through a small diameter (1-13mm) of little streams and small basins or furrows are designed to control water spreading on the land surface.

Figure 2.8 Bubbler irrigation system ("Bubblers & Bubbler Nozzles" 2017)

The efficient use and conservation of the water is important in the arid and semi-arid regions with low precipitation in order to bring the higher yield out of agricultural production. The efficient deficit irrigation methods, another irrigation method, aim to reduce water consumption by supplying less water than potential evapotranspiration. The deficit irrigation can enhance the contribution of the ground water in the dry regions for crops water use and will not result in significant loss of yield (Xiaoyu Gao, 2016).

2.5 Smart technologies in landscape and agriculture

Technology is ubiquitous and has transformed the life of the modern man and agriculture is one of the paramount sectors that modern technologies are being increasingly used. The efficient use of the water in agriculture will help the arid regions with low precipitation to tide over the difficulty of bypassing production of the food grains. Hellin et al. (2016) in their article titled, “A decision support system for managing irrigation in agriculture” supports how the automatic Smart Irrigation Decision Support System (SIDSS), can manage the irrigation in agriculture. The SIDSS approach has been validated on three commercial plantations in the South East of Spain on the citrus trees crops. The expert agronomists have examined the soil, plant and atmosphere in the region extensively to arrive at and manage the irrigation requirement of the crops and sensors were used to gather and measure the information by way of a set of variables. Hellin et al. (2016) further states that sensors will help in discerning the water surplus of the plants and soil, and thereby the right level of the water requirement can be automatically maintained using this SIDSS system. The continuous soil measurement to support the climatic parameters and to predict the right level of irrigation needs of the crops is the hallmark of this smart irrigation system and can be customized in accordance with the local perturbations.

Food security, economic pricing, low unemployment and healthy socio- economic development combined with increasing resources for the industrial units are the advantages of a well-established and sustainable agricultural sector. But efficient irrigation and agriculture in arid and semi-arid regions is a challenge not to mention the detrimental impact of the intensive irrigation practices on the ecology and environment. Todorovic, Mehmeti and Scardigno (2016) argue that achieving the eco-efficiency by way of innovative water management process and technologies. The major environmental challenges of the intensive irrigation practices for agriculture are depletion of the ground and the surface water, climate change and the eutrophication. A study conducted on the Sinistra Ofanto irrigation scheme in Southern Italy in order to understand and measure the environmental performance using a set of mid-point environmental impact categories, while taking into consideration economic performance as well, revealed the major environmental challenges (Mladen Todorovic, 2016). The depletion of the fresh water due to excessive ground water pumping and surface water use; climate change arising from the increased use of the fertilizers and emission from the diesel combustion; and the eutrophication due to the result of excessive application of the nitrogen (N) and phosphorus (P) fertilizers are common in these geographical areas. Eco efficiency and modern technology based water management can reduce the impact on the environment.

The smart utilization of the renewable energy sources has been successfully integrated into the residential and industrial requirements but has not been attempted extensively in the agriculture sector. There is no second opinion regarding the importance of agriculture in the human life and to grow and develop the food production sustainably, the low cost renewable energy sources can be integrated and adapted, smartly, into this vital sector. The design and development of a smart energy system in order to reduce the cost of the agriculture is effective and it can also help in reducing the energy cost by tapping into the Renewable Energy Source (Nasiakou, Vavalis & Zimeris 2016). Another approach based on wireless sensor has been recommended by Kehui, Deqin and Xiwen (2010). The authors state that advanced automation, self-organization and the data centric approach, the wireless sensor network can easily collect the data of field soil moisture. The dissemination of this data can help in supporting the smart water irrigation and is significantly cost effective and water saving compared to the traditional irrigation system (Kehui et. al. 2010).

Linker and Sylaois (2016) in their article titled, "Efficient model-based sub-optimal irrigation scheduling using imperfect weather forecasts" provides another means to compute the seasonal sub-optimal irrigation schedule to save the water and achieve the cost efficiency in the agriculture. The soil type, weather forecasts and the type of the irrigation system installed are taken to account to set the parameters such as the length of the short term horizon, and the amount of irrigation delivered at each trigger of the irrigation. The advantage of this sub-optimal procedure is that computations can be done under one minute making the real time implementation comparatively easy (Linker & Sylaios 2016).

China is the most populous country in the world and has successfully fed its people for the last few decades it should be understood in the backdrop of the explosive growth in the population touching an unbelievable mark of 1.4 billion. Agriculture is the largest consumer of the water in the economy and recent shift to water saving and high efficient means of production by enhancing the irrigation efficiency is notable (Jinshi Liu, 2014). The country has been exploring the impermeable channels, pipeline transportation of the water, micro irrigation, drip irrigation, sprinkler irrigation and the hole-irrigation for seeding for the last few decades. The foreign technologies like surge flow irrigation, irrigation in slopes with pipelines, rope controlled irrigation, and soil net irrigation and the subsurface irrigation have been explored as well. Negative pressure irrigation, automatic irrigation technology, irrigation without water, irrigation in airs, and irrigation with fogs are some of the new technologies being considered by the farming community and the policy makers to enhance the irrigation efficiency, to reduce the pollution and to above all to improve the comprehensive agricultural productivity of the nation (Jinshi Liu, 2014). Dynamic water management in order to ensure the sustainability of the water resources is essential to the survival of the Chinese economy. The development of the irrigation water use efficiency is the ultimate goal of the decision makers and it can be ensured by way of the software development technology. The computer network and the software will help in the collection, storage and calculation of the agricultural water saving and monitoring and scheduling of the use of water for the agriculture. This will constantly improve the water saving in the agricultural activities and contribute to the modern water management (Jia et al. 2016).

Cremades, Wang and Morris (2015) states how inefficient the irrigation system in China and the need to tide over the challenges of this low efficiency in water use. The government in China is supporting the modern irrigation technology by way of various economic incentives. The prevalent practice is to opt for household based irrigation technology instead of the community based irrigation technology. The pressure on the water resources is on the rise due to the high demand for the agricultural produce and the per capita water availability is one-quarter of the world average in the country due to this phenomenon (Cremades, Wang & Morris 2015).

The low irrigation efficiency is another reason for this deteriorating condition and the government is encouraging use of the modern technology to achieve efficiency in the water use in all the villages. Subsidies are given to encourage the farmers to adopt the modern irrigation technology and have a positive impact on the water efficiency. The general consensus is that the subsidies should be combined with the actions to promote knowledge of the advantages that are provided by the adoption of the modern irrigation technology and practices.

India, the second most populous country and a major food grain producer, is also considering and exploring the ways to stem the depletion of the ground and the surface water. Solar powered water pump with the help of the moisture sensor to control the water flow automatically is proposed from many corners as a means to the energy needs of the farmers along with conserving the grid energy that can ultimately help in conserving the water. Harishankar et al. (2014) states that solar energy is cheap and eco-friendly and solar powered irrigation system is a sustainable and suitable alternative for the farmers in India. The optimization of the water use can be achieved by controlling the rate of flow of the water from the tank to the irrigation field. Solar power will help in driving the water pump so as to draw water from the bore well to the tank while the outlet valve of the tank will be automatically regulated with the help of the controller and moisture sensor (Harishankar et al. 2014).

The increasing carbon emission and the resultant climate change is cause for concern and improved efficiency in the irrigation is considered as a way to adapt to the changes in the climatic conditions. Frisvold and Bai (2016) in their work titled, "Irrigation Technology Choice as Adaptation to Climate Change in the Western United States" explains how the climate and other factors influence the choice of selecting between the sprinkler and gravity- flow irrigation in the western states. The selection of the right technology for the irrigation has to be done in accordance with the climate change as well. The sprinkler irrigation has been found to be very promising irrigation technology in the event of climatic changes in relatively cooler and higher rainfall but is not advisable in warmer climate and drier climate change scenarios (Frisvold & Bai 2016). The study concluded that the sprinkler adoption was lower in situation where water costs are low along with higher reliance on surface water.

Smart phone and applications has permeated all aspects of our life and irrigation efficiency and the water conservation is not exempt from this as well. Bartlett et al. (2015) provides us a glimpse of how the smart phone app and technology has been adopted and embraced for finding out the solution to the water shortage in Colorado. The vibrant crops production is made possible with the help of the irrigation in the semi-arid western United States. The agricultural producers supplement the soil moisture with the irrigation in addition to the surface and ground water in Colorado (Bartlett et al. 2015). The population growth and the drought made the water very scarce in the semi-arid region of the Western part of United States and the effective and productive use of the water and irrigation is important to sustain the production of the agricultural produce. The Colorado state university took the initiative and provides the farmers, research scientists and the irrigation managers a tool to find the solution for the water shortage. If the technology is not efficient, accessible and economical, it is a disincentive for the adoption by the common farmers. The smart phone app WISE provide an easy platform for the users to access and upload information where there is cellular coverage. WISE provide the details of the evapotranspiration-based irrigation scheduling based on the soil water balance method and data queries from the Colorado Agricultural Meteorological Network and Northern Colorado Water Conservation District weather stations (Bartlett et al. 2015). The ability of the app users to find out quickly the soil moisture deficit, weather measurements can significantly help in the irrigation management of their crops.

Yuntao et al. (2016) explores the possibility of integrating the latest innovation of internet of things in the water quality monitoring. Using intelligent perception, intelligent stimulation, diagnosis and warning, the water quality and the pollution level at the source level can be diagnosed and monitored. The real time active sensing layer, smart decision layer and an interconnecting layer of water information is essential to this new architecture of smart water initiative based on the internet of things and is generally called as the hierarchy framework. There is a technical system and function framework as well in this architecture to allow it to smoothly function and deliver the objectives (Ye et al. 2016). The multi carrier network consisting of real time transporting, intelligent storage of mass data and diagnosis of the water security risk are involved in the technical system while the function framework includes the modules such as the intelligent sensing, intelligent simulation and the intelligent diagnosis coupled with early waning and intelligent regulation. Shahanas and Sivakumar (2016) further argues for the importance of the internet and how it has revolutionized the world and mentions the advancement by pointing out the Internet of Things and the increasing role it plays in our daily life. The water is the most important ingredient for the survival of the human beings and how a smart water management can help in the development and running of the so called smart cities popping up globally. The emerging technology and the Internet of Things are cost effective to be adopted by the smart cities so as to build and efficiently use the smart water management for the future in order to ensure the sustainability of the water resources and reduce the waste (Mohammed Shahanas & Bagavathi Sivakumar 2016).

Technology based irrigation and water management is best exemplified in the study titled, “Comparison of irrigation automation algorithms for drip-irrigated apple trees”. Osroosh et al. (2016) studied irrigation scheduling by developing and evaluating seven algorithms of irrigation scheduling. The plant/thermal based strategies of the time; Temperature Threshold and Crop Water Stress Index were included in this as well. Using a wireless control and monitoring system, irrigation water delivery was automatically scheduled in an apple orchard. The weather and the plant based algorithms were found to deliver enough irrigation water to the apple trees and thereby avoided the stress. The soil based approach failed to deliver enough water to the trees leading to water stress and stunted growth (Osroosh et al. 2016). Automatic irrigation on the drip irrigated apple trees proved to be efficient and can help in the water use efficiency, increased production and above all reduced cost of production. The reduction in the energy cost of pumping. Improved quality of the products is some of the other advantages of this irrigation scheduling algorithms.

Technology based irrigation has huge advantages and is more efficient compared to the time based irrigation. The rain sensor, soil water sensor and the evapotranspiration controller helps in the water savings by way of the water volume applied to the soil and the water volume drained away from the soil and the plants. In a plot study involving four types of irrigation treatment namely the automatic timer, automatic timer with rain sensors, automatic times with SWS and ET controller, the automatic timer was found to have used significantly more amount of water compared to other three treatments (Dobbs et al. 2013). In spite of the existence of the strict rules and regulations for protecting the water bodies, the water quality in many states are being degraded continuously. Fertilizers used to maintain and increase the aesthetic beauty of the turf and landscape plants in the urban centers and nutrients such as Nitrogen is increasingly applied to meet the plant requirements. The excessive rain and the irrigation carry this nutrient by leachate or runoff to water bodies and may exceed the natural capacity of the water source resulting in pollution. This can be easily prevented if we adopt the technology based irrigation instead of the time based irrigation and help in both the efficient use of the water conservation and reducing the pollution of the ground and the surface water.

Smart sprinkler has been increasingly used in firefighting and irrigation in many parts of the world. The design and he fabrication of the water sprinkler system plays a greater role in determining the efficiency of the water irrigation and use (Rahman, Zahura & Rezwan 2014). A survey performed on the application of the water sprinklers in Bangladesh and abroad by the authors has revealed that designing and developing a rotary type automated water sprinkler with the help of the Quality Function Deployment is very efficient, safe and easy to use for a variety of applications. Al Ghobari and El Marazky (2014) argue in their article titled, “Effect of smart sprinkler irrigation utilization on water use efficiency for wheat crops in arid regions” that the smart irrigation is the best solution for the scheduling of the irrigation and to quantify the water required by the plants and crops. The control irrigation system that is scheduled based on data from automatic weather station while the Smart Irrigation System was implemented and tested on the sprinkler irrigation system. The latter has been proved to be very effective in saving the water and irrigation water use efficiency. The extreme irrigation does not increase the yield or bring optimal economic benefit leading the team that undertook the study to conclude that smart irrigation based on the latest technology and the sprinkler irrigation is suitable for the agricultural crops and achieving the water use efficiency (Al-Ghobari & El Marazky 2014).

Ensuring the sustainability of our future smart cities is a top priority for the planners and decision makers. These cities are energy guzzlers with possible mobilization of different and varied knowledge centers, information technology and communication technology helping them to feed and maintain the innovation hub for the future (dos Santos 2016). The cost of production, transportation and the logistics involved in the food production are on the rise as well and supporting the ever increasing urban population and their water and energy use is a challenge and nightmare for all authorities concerned. Santos (2016) suggests Aquaponics as an integrated system suitable for the prospective smart cities. This new agricultural system encompasses all the activities and supply chain right from the producers to the consumers in addition to ensuring the organic supply of fresh produce free from the pesticides and chemicals. The smart cities do not mean the existence of the Information and the Communication Technology alone, rather an innovation hub supporting all aspects of the life of humans. Taking care of the food production and logistics, the smart cities will be able to strengthen the socio-economic progress as well.

2.6 Summary of literature review findings

The literature review presented various studies conducted on irrigation applications, technologies and the factors affecting the agriculture sector that can lead to negative impact on climate change. The various elements discussed in the previous sections carried out irrigation performance with respect to water consumption. Agriculture and landscape are one of the essential sectors in enhancing the economic growth, has a significant impact on climate change and a vial factor in enhancing the aesthetic features of the city. Following are the findings summarized:

Water challenges in Semi-arid regions: Studying the regions affected by water challenges in similar climate gave a broad view on the issue and how it can be tackled. The examples mentioned in South Asia, United States and the GCC regions argued on how groundwater and surface water are been deteriorated by the unmanaged practices of irrigation. The continuous practices will lead to a permanence threat that will increase the impact of climate change.

The literatures reviews in GCC region founded were few and others were only written in Arabic. Yet, most were confirming that the low precipitation rate in most of GCC countries is the factor behind water scarcity. Furthermore, being highly dependent on groundwater in these countries increase the negative impact of water pollution, ground water depletion and deteriorate the water table. The literature review also indicated the massive urban population occurring in GCC countries that increased the demand for water and put water sources into pressure especially with the irrational water exploitation.

Environmental Sustainability: climate change has been affecting the sustainability of the world significantly; human practices can lead to an adverse effect and cause a serious threat in the near future. Unmanaged agriculture practices especially in terms of irregular water use in irrigation will increase the negative pressure in climate and lead to unbalanced atmosphere.

Irrigation Applications: The represented studies focused on applications used mainly in semi-arid region. Almost there were similarities in the systems used such as sprinklers, drippers, and tank irrigation, yet the efficiency of the system was measured mostly on crops, neglecting the vegetation used for landscaping. The results may vary when using other type of vegetation such as ground cover, trees; palm trees and other ornamental trees, grass and seasonal flowers. Also, it was found that cost is another factor to consider when applying irrigation practices. Countries with low economic development may still use the conventional irrigation practices resulting in negative impact on environment especially water usage.

Smart Technologies: Many studies emphasized on the importance of integrating technologies and computer based systems in enhancing water usage and energy consumption. The world is in continuous growth and the current practices used in irrigation won't be efficient in the near future. The innovative technologies will take other factors in consideration such as soil moisture, local weather, and crop physiological status. Other studies integrated internet of things (IoT) in measuring soil moisture and water height by using wireless sensors. Many smart practices in irrigation decreased human intervention on site by providing a platform that facilitates the data transmission through certain network. Moreover, the smart practices enhance the efficiency and accuracy of the data obtained. Other literatures review also show the possibility of integrating sustainable features such as solar power and wind turbines in smart irrigation systems especially in terms of irrigation water pump.

Nevertheless, there were no sufficient studies on the impact of current irrigation practices in Dubai, UAE. The studies assessing the agriculture sector and landscaping in the region are very few, and mostly in Arabic therefore translation was required. The findings of literature review will be incorporated in the appropriate methodology used. Moreover, how smart technologies will enhance our current irrigation practices will be investigated thoroughly in the next chapter.

Chapter 3 Research Methodology

3.1 Methodologies used for investigation

This chapter looks into the various methodologies found in literature review. Different researchers investigated in the area of smart irrigation practices in different levels, including smart sprinklers, soil sensors, and automatic timer with rain sensor. Therefore, different methods were studied profoundly to finally choose the best approach that suits the location of Dubai, the time boundary of this research study and the available resources. Following are the different methods and approaches used by different scholars in investigating the area of smart landscape practices and smart irrigation systems.

- Field Experiment
- Survey and Data Collection
- Modeling approach
- Mixed approach

3.1.1 Field Experiment

This is the most common approach used by many researchers investigating the area of irrigation practices and smart landscaping. This method enabled the researchers to obtain valid results while observing the changes on plantation growth and water efficiency on real field experiment. Usually, the results obtained are combined with another method, for instance analytical analysis and calculation to indicate the measurement and transform the data into tables and graphs. Various factors should be taken into consideration when doing field experiment such as weather condition, factors affecting vegetation growth, soil condition and etc. This approach can last for long period of time, but when conducting an experiment for short period, other methodology should be combined for validation.

Dobbs, et al.(2013) is one of the examples that used field experiment in measuring the effectiveness of smart irrigation practices. A field experiment took place in Bahiagrass (Paspalum notatum) plot that lasted for 1 year long. The aim of the study was to assess the use of automatic timer, automatic timer with rain sensor, automatic timer with SWS and ET controller in measuring water depth and Nitrogen leached. Other scholars have also used this method in measuring the impact of using smart irrigation systems (SIS) in comparison to controlled irrigation systems (CIS) in water saving. In hot arid climate, a field experiment was conducted in the farm of college of food and Agriculture in King Saud University. Al-Ghobari and El Marazky (2014) tested sprinkler irrigation for both systems in wheat crop field. Moreover, ElWahed et al. (2015) has also conducted a field experiment at Sebha University in Libya to measure the impact of sprinkler irrigation system on irrigation uniformity and water productivity of these systems. The experiment was conducted during winter of 2009-2010 taking into consideration soil properties, operating pressure of the irrigation system, and N fertilizer. The experiment concluded that the better water distribution is, the higher the crop growth.

Similarly, Cardenas-Lailhacar & Dukes (2010) carried out a field experiment in the University of Florida to test the use of soil moisture sensor in measuring the volumetric soil moisture content. The authors used sensors from four different companies and buried them at a depth of 7-10 cm on plots with similar bermudagrass. The plots were monitored constantly by ECH2O calibrated probe at the same depth. The experiment shows a successful use of the soil moisture sensor SMS that slowed irrigation in dry periods and stoped it when it’s wet. According to the authors, 71% of the scheduled irrigation cycle were avoided by the use of SMS without effecting the quality of the turf grass. On the other hand, the authors argued that errors were very possible to occur due to inaccuracy in some readings while detecting soil moisture.

Scholars have also used graphs, tables and statistical analysis to facilitate the results obtained from the field experiments and transform the data into charts.

3.1.2 Survey and Data Collection

Surveys are usually used when measuring large sample of population's opinion. Surveys may include various questionnaire and interviews and is important to understand public's point of view and essential for research field of study. Various researchers investigated the need for smart irrigation practices through field survey. Cremades, Wang, and Morris (2015) conducted a survey to measure the impact of policy makers in promoting modern irrigation practices in China and the policies that intervene the use of these technologies. The survey was carried out in 7 different provinces and grouped into 3 groups: Traditional, household and community. The objective of this survey was to measure the current incentives put towards adapting modern irrigation technologies and to measure the subsidies and polices that intervene towards promoting irrigation technologies.

3.1.3 Modeling approach

This method can be really useful when changing variables constantly in a research study. It is less costly yet can be time consuming. The percentage of error is very limited due to the accuracy of applications used. In research studies such as this, very few used this approach in measuring the intelligent aspect of landscape and agriculture. An example found in a study conducted by (Jia, et al. 2015) in which researchers used MSR and PCA model to measure the efficiency of water used in irrigation in China. Yet, another approach was also used to support and validate the modeling approach. The resulted data was analyzed through various calculations and statistics. This approach seems to get efficient results yet time consuming and complicating especially with the intensive calculation particularly when various irrigation practices are measured at once.

3.1.4 Mixed approach

This method includes combining two methods from the previous approaches. Many found to use mix-method approach when measuring various parameters especially when combining qualitative and quantitative data. In the study of this area, many tend to use this approach to facilitate their measurements and data obtained. Mwongera et al. (2016) used this approach in measuring the impact of Climate Smart agriculture (CSA) on climate change. Especially after Paris agreement COP21 many countries looked into various contributions that will lessen the negative impact. The author used combination approach called CSA-RA which is a combination of rapid rural appraisal (RRA) and participatory rural appraisal (PRA). For rapid information, RRA approach is used to extract the knowledge from farmers and experts. RRA extract information related to household, economic resources, social information related to education, the size of the household and farm characteristics. When looking into approaches that engage community members through various participatory exercises, CSA utilize PRA approach. PRA empower stakeholders to evaluate their thoughts on various problems such as the impact of climate change or agriculture, agriculture management systems, the availability of natural resources.

3.2 Chosen research methodology and justification: Field Experiment

Many researchers in this field domain used experiment method as their way of validating the efficiency of agricultural parameters especially in terms of irrigation Practices. Researchers in this field of study tend to have a real life experiment in more than one season to validate various parameters based on the results obtained. Many aspects are taken into consideration such as weather condition, soil type, drainage; irrigation system used and type of plant cultivated. Pilot projects tend to test and assess the integration of certain technology and measure its impact and feasibility in a larger scale.

For this dissertation, the author found that field experiment methodology is the most essential method due to many factors that will be analyzed in this research study. The field experiment will be complemented by simple calculation and statistical analysis to validate the results and compare it to the base case. The benefit for using this approach is that the author would be able to measure the impact of using certain technology in real life experiment and assess its impact on the base case. Moreover, field experiment is important in this research study to measure the water use efficiency and the daily flow rate and observe its impact on plantation growth and health. It is also essential to evaluate the impact of using soil water moisture at various depth in determining the irrigation schedule and how this system will enhance the water usage in landscaping. Using other methodologies such as modeling and survey won’t be effective in this study as the output won’t be efficient in determining the effectiveness of the technology on the base case. The output obtained from the field experiment can help in providing a strong platform and understanding on the efficacy of the technology used.

Yet, due to time limitation and cost of equipment required to allocate for the experiment, it will be conducted in shorter period of time to measure the amount of water required for healthier growth of plant in the harshest climatic condition. Moreover, as treatment water used for irrigation practices in Dubai is in short supply in summer, the winter condition is not to be taken into consideration in this dissertation.

3.2.1 Site description, field feature and irrigation practices

This experiment was conducted at Warsan Nursery of Dubai Municipality during the summer of 2017 using smart soil moisture sensors. Dubai coordinates are latitude: 25.2048° N, longitude: 55.2708° E and is approximately 52ft above sea level.

The climate in the area is classified as hot arid with high humidity in some days. Table 3.1 indicates the climatologically data measured during the field experiment. The site is already cultivated and it should be noted that the two irrigation methods used are; drip irrigation for the shrubs shown in Figure 3.1 and sprayers used for the field grass.

Figure 3.1 Shrubs (*Bougainville)* irrigated by drip irrigation. (Source: author)

Table 3.1 Metrological data of the experiment site ("Al Wasl, United Arab Emirates Weather Forecast and Conditions - The Weather Channel | Weather.com" 2017)

Month	**Max Temp °C**	**Min Temp °C**	**Humidity %**	**Rain (mm)**	**Average Wind speed $m.s^{-1}$**
July	41	35	38	0%	10 km/h
Aug	43	34	18%	0%	11km/h
Sep	41	32	34%	0%	16km/h
Oct	37	29	60%	0%	21km/h

Rain Bird ESP-LXME Controller is situated on site adjacent to the selected plot to regulate the landscape irrigation system; another smart controller is installed to compare the values using smart irrigation system with current controlled irrigation system. The chosen site for the field experiment is highly exposed to sun light with no obstacles that might hinder sensors readings. The plot is covered by grass and the edges are surrounded by shrubs and seasonal flowers.

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Appendices:

Appendix A: Soil test in Warsan Laboratory

النتائج Results					
Method	Recommended optimal range	**S. 2**	**S.1**	**Pot**	كود العينة **Sample code**
Dry weight	According to irrigation conditions	**3.5 %**	**6.59 %**	**20.7 %**	Moisture %
1:1 Extract	< 5.1 **Strongly acid** ; 5.2–6.0 **moderately acid** ; 6.1–6.5 **slightly acid** ; 6.6–7.3 **Neutral** ; 7.4–8.4 **moderately alkaline** ; >8.5 **Strongly alkaline** **General optimal rang for most crops 6-8.2**				PH
Dry weight					Carbonates %
1:1 Extract	0-2 **(non saline)** ; 2-4 **Low salinity** ; 4-8 **Mild salinity** ; 8-16 **High salinity** ; >16 **Severe salinity** **General optimal rang for most crops(0-4)ms/cm**				Electrical conductivity التوصيل الكهربي
1:1 Extract					TDS الأملاح الذائبة
Khajeldahl	**Low** ; **Sufficient** 0.10 -0.15 % ; **Excessive**				N %

Colorimetric	**Low** <10	**sufficient** 10–20	**High** 20-40	**Excessive** >40					P(ppm)
AAS	**Low** <150 ppm*	**Sufficient** 150–250 ppm	**High** 250–800 ppm	**Excessive** >800 ppm					K(ppm)
Sufficiency or optimal rang of nutrients depends on and differs according to the crop needs									Recommendations **التوصيات**

رئيس شعبة المشاتل والمختبرات	**مسئول المختبرات**	**محلل كيميائي زراعي**

Appendix B: Site images

Appendix C: Sensor Manual was taken before the integration of the smart irrigation system (SIS). The condition of the grass as shown indicates a very low maintenance in some area with grass disease covering some parts, due to high temperature, low water pressure and a probability of soil disturbance. Therefore, an action was required to maintain the grass and manage the water pressure of the sprayer nozzles prior to the field experiment.

The site was divided into 4 different plots according to the hydro-zones of the irrigation systems: two plots were irrigated by the traditional irrigation system that includes drippers and sprayers and this was numbered as Plot (2) shown in

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Appendices:

Appendix A: Soil test in Warsan Laboratory

Results										
Method	Recommended optimal range						**S. 2**	**S.1**	**Pot**	**كود العينة Sample code**
Dry weight	According to irrigation conditions						**3.5 %**	**6.59 %**	**20.7 %**	Moisture %
1:1 Extract	< 5.1 **Strongly acid**	5.2–6.0 **moderately acid**	6.1–6.5 **slightly acid**	6.6–7.3 **Neutral**	7.4–8.4 **moderately alkaline**	>8.5 **Strongly alkaline**				PH
	General optimal rang for most crops 6-8.2									
Dry weight										Carbonates %
1:1 Extract	0-2 **(non saline)**	2-4 **Low salinity**	4-8 **Mild salinity**	8-16 **High salinity**	>16 **Severe salinity**					Electrical conductivity التوصيل الكهربي
	General optimal rang for most crops(0-4)ms/cm									
1:1 Extract										TDS الأملاح الذائبة
Khajeldahl	**Low**	**Sufficient** 0.10 -0.15 %	**Excessive**							N %
Colorimetric	**Low** <10	**sufficient** 10–20	**High** 20-40	**Excessive** >40						P(ppm)
AAS	**Low** <150 ppm*	**Sufficient** 150–250 ppm	**High** 250–800 ppm	**Excessive** >800 ppm						K(ppm)
Sufficiency or optimal rang of nutrients depends on and differs according to the crop needs										Recommendations **التوصيات**
رئيس شعبة المشاتل و المختبرات				**مسئول المختبرات**						**محلل كيميائي زراعي**

Appendix B: Site images

Appendix C: Sensor Manual.

Figure 0.1 Selected plot for the field experiment. (Source: author)

It was controlled manually based on the timings set by the irrigation engineers at the main STP controller. The timings are set based on plants requirement and a calculation made earlier by irrigation experts in the field of irrigation. Figures 3.3 and 3.4 show that controllers for drip irrigation system hydro-zone and sprayer irrigation system hydro-zone with water capacity for each system.

Figure 0.3 Drip controller with 3.30 litters water capacity. (Source: Author)

Figure 0.4 Sprayer controller with 5.04 litters water capacity. (Source: author)

The second plot, numbered Plot (1) used smart moisture sensors: irrigated by the same irrigation system; drippers and sprayer. The number of sprayers assigned to the spray solenoid valve is approximately 64 sprayers at a total area of 30*30 m^2. The sprayer body used is SAM+PRS adjacent to the existing Rain Bird ESP – LXME controller. Moreover, new HE-VAN nozzles were replaced with the existing nozzles for better results. On the other hand, the size of the solenoid valve used for the dripper is 1.5” (38.1mm) for 1100 linear meters dripper line. The topography of the selected site is flat and the type of soil in the field is sandy loam. Type of soil plays a significant role in determining the amount of water it can hold in its particles. Three different samples of soil have been taken at different depths and tested in the laboratory of Warsan nursery to understand the moisture level prior to the test. Results will be shown in the next chapter. Figure 0.2 elucidates the four soil type and its potential water content. As shown in the figure, the different types of soil and its water capacity. The soil used in agriculture and landscape projects in most of Dubai region is sandy loam which is a mixture of sand and clay. It’s normally better in terms of allowing drainage comparing to clay. Sandy loam is also known of its limited water holding capacity and it reaches saturation point faster than clay that is known of its high water holding capacity. Understanding the type of soil used is essential when using sensors to estimate the amount of moisture available in the soil that sensors can detect while operating its irrigation cycle.

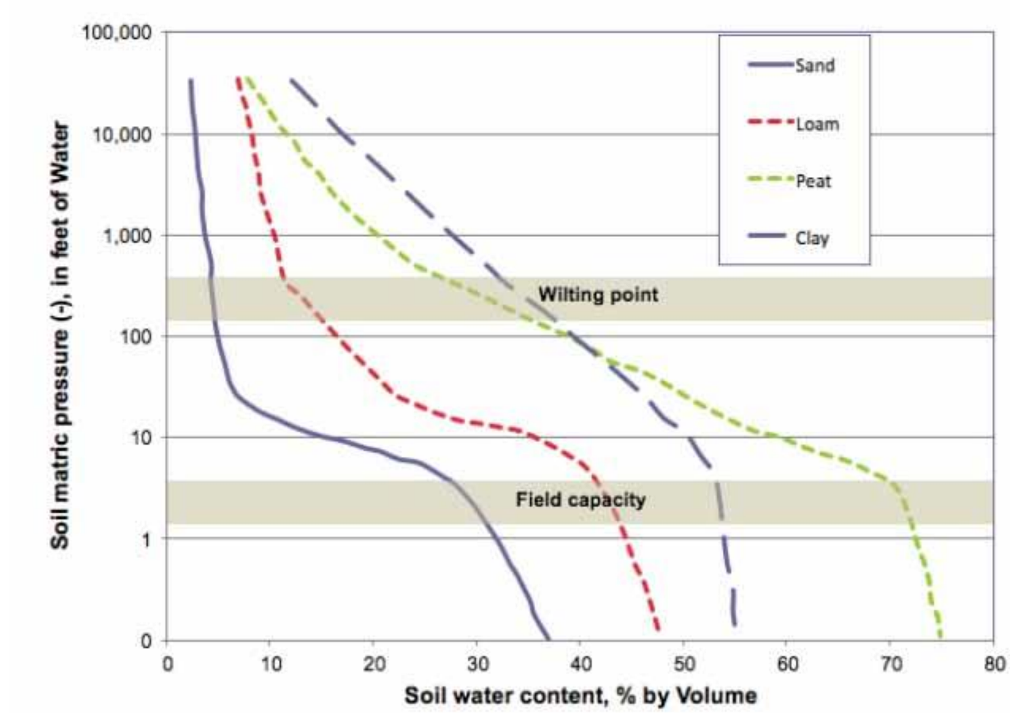


Figure 0.2 Soil texture and its metric potential in relationship to volumetric water content. (Source: Sample et al. 2016)

3.2.2 Smart and sustainable irrigation solutions available in the UAE market

The market of UAE has developed a wide range of irrigation technologies that has been used widely by the private sectors and developers in commercial and residential projects. The need to enhance the landscape and agriculture practices in UAE encouraged many investors to seek for various technologies and bring it to the local market. The current technologies available in the market are promoting the idea of water conservation, energy reduction, and smart solutions. The technologies available in the UAE's market are various and vast, starting from smart controllers, sensors, and ending with software applications. Private communities in Dubai such as Silicon Oasis has introduced a sustainable method of irrigation such as subsurface drip irrigation that helped in reducing water by 40% while increasing the quality of plants according to the supplier ("Rain Bird: Sprinkler Systems, Commercial Irrigation, Residential Irrigation, Lawn Sprinklers, Drip Irrigation, Golf Course Irrigation and Agricultural Irrigation" 2017). Moreover, Dubai Municipality is also testing the use of weather station in the current and future projects. A pilot project was conducted in AlQuran Park and a weather station was placed to irrigate the cultivated plants. Weather station is essential in determining the required irrigation water by collecting and storing weather data from the site. The data obtained from the sensors are highly accurate and reliable with an easy access to the information needed through a controller system. Soil moisture sensors were used in a pilot project in Sea Palace in Abu Dhabi, private Sheikh palace. The system was integrated in the field grass of the green house by Gulf Water management. According to Ramadan (2017) the controlled experiment was able to save approximately 40% of water from the irrigation system. Other sensors available in the market includes solar sync, rain click, flow click, ET system and soil click. Individuals have been also encouraged and motivated to enhance the sustainability and smart solutions in their gardens. Hydrawise cloud software is water management software that enables homeowners to have an in-depth water management through a user-friendly application. The application can easily send a text or a notification when a pipe or sprinkler is damaged and has stopped irrigating. In addition, the end-user can easily stop irrigating without the need to visit the site. Hydrawise software can be downloaded in any iPhone or android in addition to a web access.

3.2.4 Smart system installation, component and function

The technology used for this field experiment is smart soil moisture that evolved around monitoring the reduction in operation time (water consumption saving) versus the regular devices operation. The technology is designed to measure the amount of moisture available in the soil to eliminate overwatering and the concept of water saving devices and techniques. The technology was chosen for this research study for various reasons. First, Soil moisture sensor will enable landscape designers, agriculture engineers and irrigation engineers to address numerous questions related to irrigation timing, duration, water infiltration to the soil, and the required depth for irrigation. Second, it is easy to install and connect to the irrigation system. There is no need to dig or build a specific structure for the installation, but a simple sensor buried in the root zone of the plants that can easily assess the amount of water in a soil. A timer and automated controller that can collect data directly to the computer is also needed. This can save money and time for many future projects. Third, water is on high demand especially in agriculture sector of Dubai, and utilizing the amount of moisture and water available in the pores and particles of the soil can contribute towards water conservation.

The smart device kit integrates many aspects that enhance the plant production and significant impact in water usage. Comparing to the various devices available in the local market, this affordable device can be easily installed in commercial and residential applications.

The technology was installed according to the manufacturer's instructions and can be easily customized according to the cultivated crops and plants and the size of plots. The soil moisture sensor was programmed and designed in consideration to environmental condition, precipitation events, and crop type.

The component of the soil moisture sensor kit includes:

- Controller User Interface
- In-Ground Soil Moisture Sensor
- Anodized, rust-proof screws, 1.5" (two per package)
- Wire nuts – 5 blue, 2 gray, 1 yellow
- Temperature sensor

This type of system promotes the use of IoT especially with the integration of sensors and digital controllers that can be regulated effortlessly. The sensors are designed to monitor moisture level at the root zone and start the irrigation cycle when required; therefore, overwatering issues are eliminated. Moreover, the device facilitates the data obtained by providing a watering history of 7 irrigation cycles. With soil moisture, there is no need to adjust the controller daily, yet, the controller can be programmed one time to water and the soil sensors will be determining the amount of water needed. Figure 0.3 elucidates the simple steps of installation.

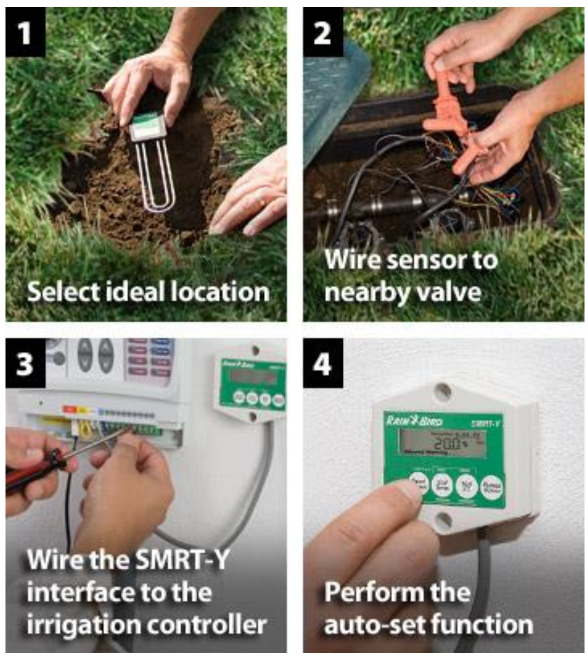


Figure 0.3 The installation of SMRT-Y Soil Moisture Sensor Kit ("Rain Bird SMRT-Y Soil Moisture Sensor Kit" 2017)

A watermark monitor has been installed on site to record the periodic readings received from the soil moisture and scheduling changes can be made on spot. There is also "In-field" display that assists in checking the readings in the field. The existing nozzles will be replaced with HEVAN – High Efficiency Nozzles. And XFD – Pressure compensating drip line will replace the old drip lines. Two wireless components added to this experiment; first is the buried sensor installed in the ground at the field area close to the controller. Second is the receiver. The selected site contains a nearby valve of Rain Bird, and Figure 0.4 showing wire sensor installation on the existing valve. Moreover, flow Sensor (1.5”) is also installed on existing sub main pipe just before the selected existing solenoid valve. To ensure a proper communication between the sensor and the controller, a smart flow module has been installed inside the current controller.

Figure 0.4 Wire Installation on the existing valve (Source: Author).

Prior to installing the sensors in the ground, it has been soaked in a water till it’s saturated for several hours then kept to dry (wet-dry cycle) to improve its response when first irrigating. The sensors then are buried in the grass field in undisturbed soil at a depth of 30 – 60 cm. Each sensor is located at a point that is closer to an irrigated area in several locations.

For the dripper, it is placed within 10-15 cm deep. Choosing the right depth is essential to avoid disturbance and sensor damages. The ideal moisture threshold as per the supplier’s instruction is 20% however this may vary depending on the landscape and the growth of the plants. This can be easily changed depending on how healthy the landscape is and the threshold can be decreased to save more water. Table 0.1 below elucidates soil type and its moisture threshold along with field capacity. The data can be simply read onsite through the monitoring station data logger or available in a computer as an excel sheet.

Table 0.1 Field capacity and moisture threshold for various soil type ("Rain Bird: Sprinkler Systems, Commercial Irrigation, Residential Irrigation, Lawn Sprinklers, Drip Irrigation, Golf Course Irrigation and Agricultural Irrigation" 2017)

Soil Type	Typical Field Capacity	Suggested Moisture Threshold
Sand	15%	12%
Loamy Sand	18%	14%
Sandy Loam	21%	17%
Sandy Clay Loam	29%	23%
Loam	31%	25%
Sandy Clay	33%	26%
Silt Loam	35%	28%
Clay Loam	36%	29%
Silt	38%	30%
Silty Clay	40%	32%
Silty Clay Loam	40%	32%
Clay	44%	35%

3.2.5 Smart sensor operation

To calculate the irrigation water requirement for the selected plot, daily values were first determined taking into consideration the metrological data, plants' requirements and water application efficiency. The data were later saved and automatic irrigation is set and controlled via main STP controller and the labors onsite. The selected plot for this field experiment contains field grass that is irrigated for 20 minutes per day and shrubs and seasonal flowers 45-60 minutes per day. The experiment was conducted for 3 months (mid -July, August, September, and mid-October). The buried sensor detects the amount of moisture available in the soil and sends a signal to the controller. The controller on the other hand sends a signal to the timer and the timer sends another signal to the solenoid valve to prevent irrigating when water reaches certain threshold. Figure 0.5 elucidates the threshold idea and when water is allowed or suspended depending on soil saturation.

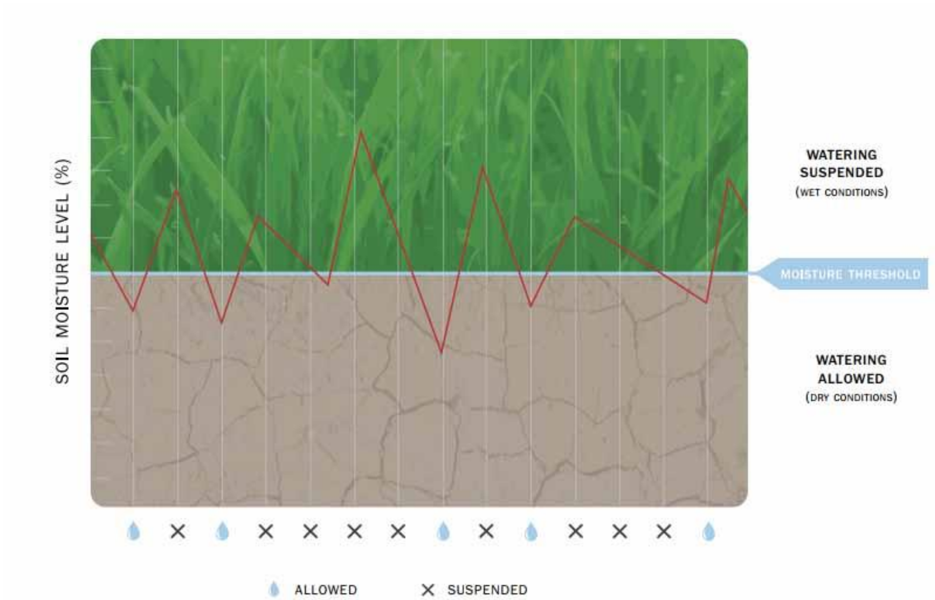


Figure 0.5 Soil moisture threshold interpretation ("Rain Bird: Sprinkler Systems, Commercial Irrigation, Residential Irrigation, Lawn Sprinklers, Drip Irrigation, Golf Course Irrigation and Agricultural Irrigation" 2017)

3.2.6 Measurement assessment

The results obtained from using soil moisture sensor as a smart irrigation system (SIS) will be compared to the traditional system which is the controlled irrigation system (CIS). The comparison is made based on water consumption, the time required for operating both systems and plants growth. As mentioned earlier in this study, the goal is to reduce water consumption and enhance the irrigation practices by improving irrigation management on site. The results below will show sensors readings from July to beginning of October. As mentioned earlier this experiment results will show only one season which is summer due to study limitation along with looking into the issue from the peak usage irrigation water.

The time required for both systems will also determine plant’s effectiveness growth. Overwatering causes environmentally damages and economic loss, and that should be extremely eliminated. Plants growth is assessed based on its leaves color; the greener it is, the healthier it indicates. Moreover, a close observation on plants disease that can affect the leaves or the roots should be taken into consideration. The next chapter will show the condition of the site while using the current system of the controlled irrigation (CIS) and the operation time in opposed to the smart irrigation system (SIS).

Chapter 4 : Results and discussion

The field experiment results from the site in Warsan Nursery have been analyzed profoundly to understand the feasible solutions in terms of environmental, economic, and irrigation scheduling management. This section of the study aims to successfully predict the plants irrigation needs based on the information provided by the device. It will also analyze the results obtained and additional calculations and financial assessment will be made to address the economic viability.

The analysis below will perform to assess the significant differences between the existing irrigation system and the smart irrigation system by the integration of soil moisture system. Moreover, taking into consideration the short period experiment, further studies will be considered after this research study to obtain various results in different months and season throughout the year.

4.1 Environmental Analysis and Sustainability

The environmental aspects of the study will be looked upon by evaluating the primary water flow of each configuration and the healthier growth of the plants by examining the difference of the leaves color along with examining the roots of the shrubs and the brightness of its leaves color. Proper irrigation management results to preserving natural environment and its sustainability. Energy is also a parameter to consider for future study, yet it has not been considered for this field experiment due to time limitation and availability of resources.

4.1.1 Base Case Analysis – Scenario 1: Controlled irrigation system (CIS)

In scenario 1 both irrigation systems; dripper and sprayer irrigation are operated manually onsite by certain number of labors. The main pipe line of water quantity and timing are monitored and recorded via a controller and the main STP in Sewerage and irrigation network department by

Dubai Municipality. Yet, the sub pipe lines are regulated on site. The daily irrigation schedules varies on daily basis. For instance, some days it will be irrigated early morning, other days it can be later in the afternoon. The variations in irrigation schedules are not based on weather condition, soil water content or plantation need but the decision of the labors on site. The water flow of the irrigation system in Warsan Nursery is approximately 4800 m^3 / day. Table 4.1 shows the water requirement as per the existing plants used for this research study in the following months (July, August, and September).

Table 4.1 Water requirement for the planted vegetation in the selected plot (Atries 2017)

Month	**July**	**August**	**September**	**October**
Shrubs (*Bougainville)* Lt/shrub/day	15	15	10	10
Grass (Lt/m^2/day)	8	8	5	5

The duration of the current irrigation system can be divided or irrigated at once. For instance, the 20 minutes set for the grass can be irrigated as 10 minutes in the morning and 10 minutes in the evening. The same thing with the Bougainvillea, 45 minutes can be divided as 20 minutes in the morning and 25 minutes in the evening. The goal set for the controlled irrigation system (CIS) that the plants get it's fully water requirement set for each type. The water budgeting set for this system is 100% at its peak water requirement and both systems are daily active. The daily water duration for the field grass using sprayer and sprinkler is 20 minutes per day. While the daily water duration for the planted shrubs using dripper is between 45 - 60 minutes per day. Table 4.2 shows the valve schedule of the irrigation system settings for different days picked randomly by the author to assess the water scheduling using CIS. The days picked are every 2-3 weeks based on the significant changes that might occur to the plants and can be documented and compared for the study.

Table 4.2 Solar Controller Valve schedule – Warsan Nursery (Khan 2017)				
Station	**Time 1**	**Time 2**	**Time 3**	
20/07/2017				
	6:30	**19:00**	**20:00**	
1		60 min		Drip
2			60 min	Drip
3	20 min			Sprayer
4	20 min			Sprayer
5	20 min			Sprayer
6	20 min			Sprayer
01/08/2017				
	6:30	**19:00**	**20:00**	
1	30 min		30 min	Drip
2		60 min		Drip
3	10 min		10 min	Sprayer
4	10 min		10 min	Sprayer
5	10 min		10 min	Sprayer
6	10 min		10 min	Sprayer
15/08/2017				
	7:00	**16:00**	**20:00**	
1	60 min			Drip
2			60 min	Drip
3		20 min		Sprayer
4		20 min		Sprayer

5		20 min		Sprayer
6		20 min		Sprayer
01/09/2017				
	13:30	**19:00**	**20:00**	
1		60 min		Drip
2			60 min	Drip
3	20 min			Sprayer
4	20 min			Sprayer
5	20 min			Sprayer
6	20 min			Sprayer
19/09/2017				
	7:00	**16:00**	**20:00**	
1		45 min		Drip
2		45 min		Drip
3	20 min			Sprayer
4	20 min			Sprayer
5	20 min			Sprayer
6	20 min			Sprayer

The schedules mentioned in Table 4.2 are set regardless of whether condition or soil water requirement. The changes in timing are mostly to avoid water splash to labors while working in the afternoon or the high temperature. Moreover, the irrational management of irrigation timings due to miscommunication between the labors on site and the irrigation engineers has also resulted in poor irrigation supervision.

The effect of the current controlled irrigation system (dripper and sprayer) scheduling on the plant's growth were investigated and observed by examining the continuous growth of the plants throughout the experiment and the minimization of the fungus disease in the grass area. Growth quality for both; field grass and shrubs are shown in Figure 4.1 and Figure 4.2. Due to harsh climatic condition and unmanaged irrigation scheduling, the grass has shown a negative germination.

The controlled irrigation system continued in causing dryness in the turf grass and fungus disease in many areas turning the grass into brown color. Moreover, as grass is in high demand of water, especially in high temperature, the low water pressure of the current sprayer system is not improving the extreme dryness shown in Figure 4.1. The picture of the turf grass was taken in July 2017, prior to the field experiment. On the other hand, figure 4.2 is showing the Bougainvillea planted at the back side of the selected plot.

Figure 4.1 Field grass showing fungus disease spreading in many part of the grass. (Source: Author)

Figure 4.3 shows an active dripper system for the bougainvillea. The system was also active early morning with minimal supervision causing overwatering in the drip irrigation as shown in the image below.

Figure 4.2 Bougainville planted on site irrigated by drippers. (Source: Author)

Figure 4.3 shrubs overwatered by drip irrigation. (Source: Author)

To calculate the water flow of the sprayers used in the selected plot in the month of July, August, September and October, Table 4.3 shows the water flow for both water pressures 1.0 and 1.5 bars. The lower pressure was mostly founded in July and August, while 1.5 bars is the water pressure for September and October. Note that the incoming water to Warsan Nursery is dependent on treatment water, and it's noted that in summer the incoming water is very low compared to winter and this is another issue to take into consideration.

Table 4.3 water flow calculation of the sprayer used (base case configuration)

Nozzle radius	**No. of Nozzles used**	**pressure**	**Water flow**
360° (Full circle)	36	1.0 bar	Water flow = 0.60 x 36 = 21.6 m^3/h 0.36 m^3/min Volume of water delivered over 40 min = 14.4 m^3/ min Which is equivalent to **= 7.2 m^3 over 20 min**
		1.5 bar	Water flow = 0.78 x 36 = 28.08 m^3/h 0.46m^3/min Volume of water delivered over 40 min = 18.4 m^3/ min Which is equivalent to **= 9.36 m^3 over 20 min**
180° (Half)	24	1.0 bar	Water flow = 0.30 x 24 = 7.2 m^3/h 0.12 m^3/ h Volume of water delivered over 40 min = 4.8 m^3/ min Which is equivalent to **= 2.4 m^3 over 20 min**
		1.5 bar	Water flow = 0.36 x 24 = 8.64 m^3/h 0.144 m^3/ h Volume of water delivered over 40 min = 4.76 m^3/ min Which is equivalent to **= 2.88 m^3 over 20 min**

90°	4	1.0 bar	Water flow = 0.15 x 4 = 0.6 m^3/h 0.01 m^3/min Volume of water delivered over 40 min = 0.4 m^3/ min Which is equivalent to **= 0.2 m^3 over 20 min**
		1.5 bar	Water flow = 0.18 x 4 = 0.72 m^3/h 0.013 m^3/min Volume of water delivered over 40 min = 0.52 m^3/ min **= 0.26 m^3 over 20 min**
Total water volume delivered in 20 min		**1.0 bar**	**9.86 m^3/min**
		1.5 bar	**12.5 m^3/min**

To calculate the water flow using the traditional system, it is essential to understand first the water requirement for the selected plot. As mentioned earlier, the water requirement for the field grass is 18 litter/m^2/day. The selected plot is 30x30 for each system in which the water requirement of the plot is elaborated in the following formula (Atries 2017):

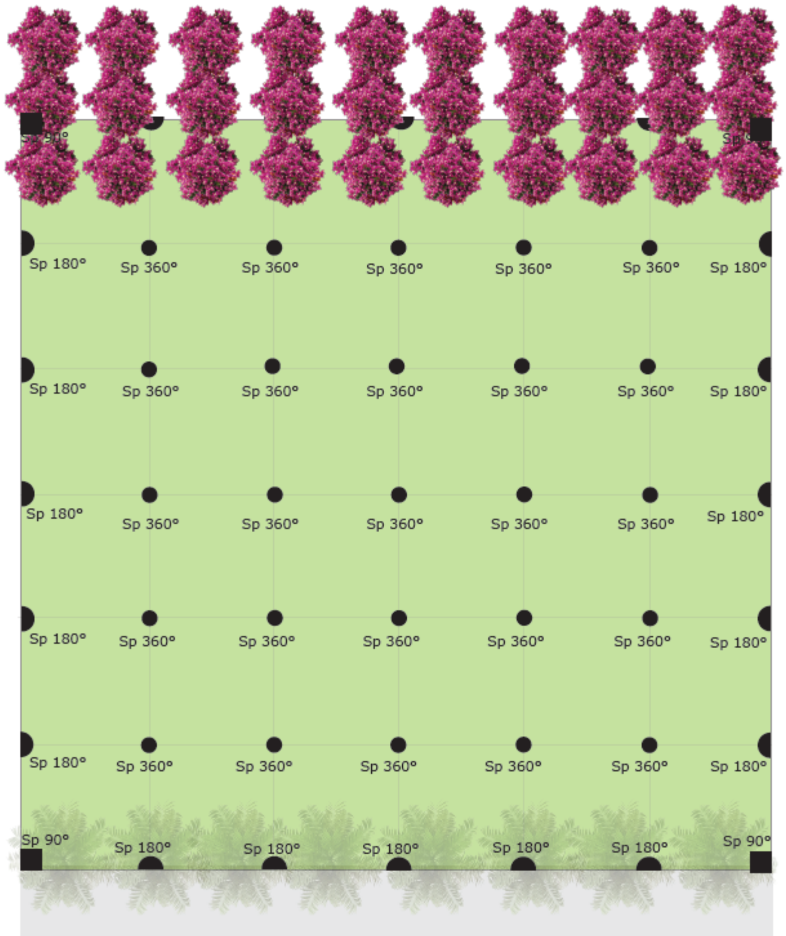
$$water\ requirement\ of\ the\ selected\ plot = \frac{900 \text{ x } 18}{1000} = 16.2 \text{ m}^3 \text{ /day}$$

The current sprayers used in the selected plot for the turf grass are SP 360°, 180°, and 90°

4.4 illustrates the various sprayers radius on the selected plot.

The total water volume per hour for all sprayers calculated from Table 4.3 = 38.22 m^3/h

$$\frac{60 \text{ mi}n\ x\ 16.2}{38.22} = 25.4 \text{ m}^3\text{/min}$$



4.4 Location illustration of Sprayer radius on site. (Source: Author)

Table 4.4 Water flow calculation for the Shrubs (base case configuration)			
No. of Plants (*Bougainvillea*)	**Number of Drippers used**	**Operation time**	**Water flow/dripper**
400	400	45 – 60 min	1 gal/ hr (0.0038 m^3/ hr)

According to Table 4.4 the total water flow per 1 gallon per hr per dripper/plant is

$$\frac{400\ x\ 1}{x} = 400\ gallon\ /hr$$

Actual water volume delivered during operation: ⟶ 1 gallon 60 min

400 gallon ⟶ 60 min

X ⟶ 45 min

X= 300 gallon /45 min
($1.13\ m^3$ / 45 min)

4.1.2 Case analysis using soil moisture senor – Scenario 2

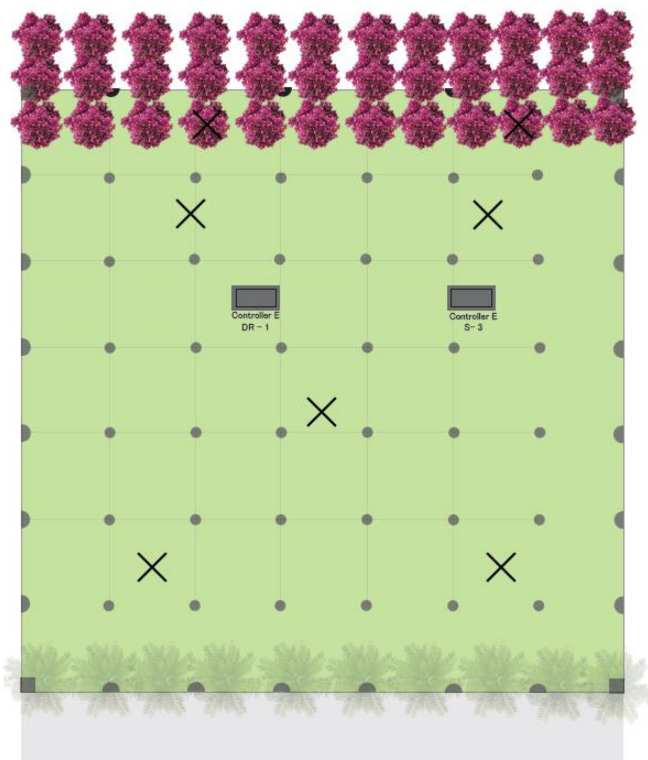
Prior to the experiment, three different samples of the soil from the selected plot were taken to the lab to estimate soil moisture level. The samples were taken early morning, prior to the irrigation cycle. Table 4.4 illustrates soil moisture characteristics that were essential to understand moisture content and the various properties affecting the water available in the soil. The table shows the content for the three different samples; two were taken from the turf grass at two different depths labeled as Sample 1 and Sample 2 and one from the pots used for the shrubs. The soil water content in the Bougainvillea pot has shown a higher percentage compared to the soil moisture taken from the field grass. The availability of moisture in soil tested has a positive result in decreasing the irrigation duration of the bougainvillea.

The test was taken in one month due to time limitation and the required time to assess the soil in the laboratory. For valid results, samples should be taken at different seasons in different time.

Table 4.5 Laboratory test results of 3 different soil samples to assess soil moisture content

Samples	**Sample 1 (15 mm)**	**Sample 2 (30 mm)**	**Pot (Bougainvillea)**
Moisture %	6.59 %	3.5%	20.7 %

Figure 4.5 Illustrates the soil moisture sensor location on site, represented by the sign X. 5 sensors were located in the turf grass at different depths. For instance, one is located closer to the root zone, while others are in the upper side with approximately 15 mm depth. This is to give better results of the crop uptake of water. On the other hand, 2 sensors were placed for the shrubs.



4.5 Sensor location and the irrigation system associated

In this scenario, the goal is to validate the effectiveness of using soil moisture sensor in detecting the amount of water available in the soil which as a result manages the irrigation requirement as per the need. The results obtained might be lower than expected comparing to what could be achieved by retraining the site and system. The experiment was conducted during the peak period of water usage in Dubai which is July and August and the beginning of fall in September and October.

The numbers in Table 4.6 represent moisture level tension in the soil. In case the soil is dry and moisture level is down the data shows a very high number (250+) but that is considered extremely dry.

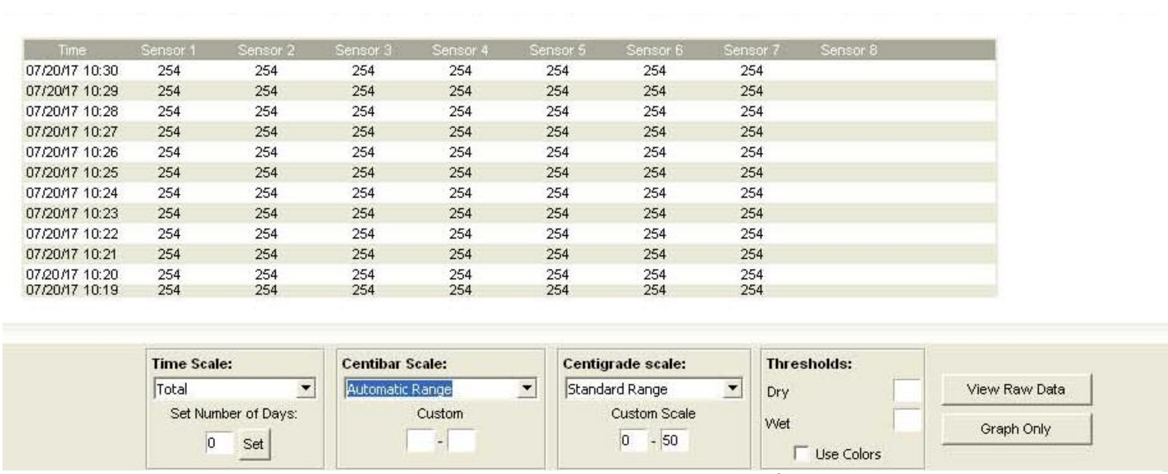
Table 4.6 Soil sensor readings and description ("Irrometer Soil Moisture Basics" 2017)	
Readings in cbars	**Description**
- -	Dry or non-conditioned sensor
0 – 10	Saturated soil
10 -30	Soil is adequately wet (except for coarse sands which are beginning to lose water)
30-60	Usual range for irrigation (except heavy clay soils)
60-100	Usual range for irrigation in heavy clay soils
100-200	Soil becoming dangerously dry

Furthermore, according to the soil used in the selected plot and in most of Warsan Nursery, Table 4.7 shows the recommended values of soil moisture sensor that allow the irrigation system to operate based on various soil types. The type of soil used in this study is sandy loam, and according to table 4.7, the readings should be between 50 – 70 centibars.

4.7 Reccomended soil moisture tention based on soil type (Orloff, Hanson & Putnam 2003)

Soil Type	Soil Moisture Tension (centibars)
Sand or loamy sand	40-50
Sandy loam	50-70
Loam	60-90
Clay loam or clay	90-120

The results mostly obtained in July and August in which the heat is in its peak level and the evaporation rate is high. The results have shown many similarities in these two months with slight fluctuation later in September and October. The data shown obtained from 7 different sensors spread in the selected plots used for sprayer and drip irrigation system in different days. Due to similarities and consistency in the data found, and an error occurred in days where sensors were not able to detect the moisture level, only certain data will be shown to explicate the amount of moisture contained in the soil at certain depth and how this led to a change in the irrigation management. The results shed light on sensor readings in one season only which is summer, taking into consideration that winter might have completely different results especially when the soil is wet during rainfall season and irrigation bypasses occur. This could result in even more water and economic savings. The tables will show soil moisture tension readings for the sprayers and drippers spread in the selected plot. The system irrigates when the sensor approaches the recommended values shown in table 4.7. The first results shown in Table 4.8 indicates similar values among the different sensors, yet with a very high sensor readings due to an error occurred while connecting the sensor to the controller.



Time	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6	Sensor 7	Sensor 8
07/20/17 10:30	254	254	254	254	254	254	254	
07/20/17 10:29	254	254	254	254	254	254	254	
07/20/17 10:28	254	254	254	254	254	254	254	
07/20/17 10:27	254	254	254	254	254	254	254	
07/20/17 10:26	254	254	254	254	254	254	254	
07/20/17 10:25	254	254	254	254	254	254	254	
07/20/17 10:24	254	254	254	254	254	254	254	
07/20/17 10:23	254	254	254	254	254	254	254	
07/20/17 10:22	254	254	254	254	254	254	254	
07/20/17 10:21	254	254	254	254	254	254	254	
07/20/17 10:20	254	254	254	254	254	254	254	
07/20/17 10:19	254	254	254	254	254	254	254	

Table 4.8 Soil Sensor readings on July 20th, 2017

Error! Reference source not found. shows soil moisture tension readings on August 1st , 2017 for b oth systems, sprayer labeled as SP and dripper labeled as DR. The sprayer irrigation system operated for 20 minutes starting from 10:30 AM, while the dripper was operated for approximately 40 minutes with similar starting point. As shown in the figure, the soil moisture readings are between 49 – 50 Centibars for both irrigation systems, which is the usual range of irrigation for the type of soil selected in this study as explained earlier in Table 4.7. The similar values of the sensor readings are also an indication of the consistency of water content in the soil at the selected plot. Fewer variations in soil characteristics can decrease the amount of sensors used.

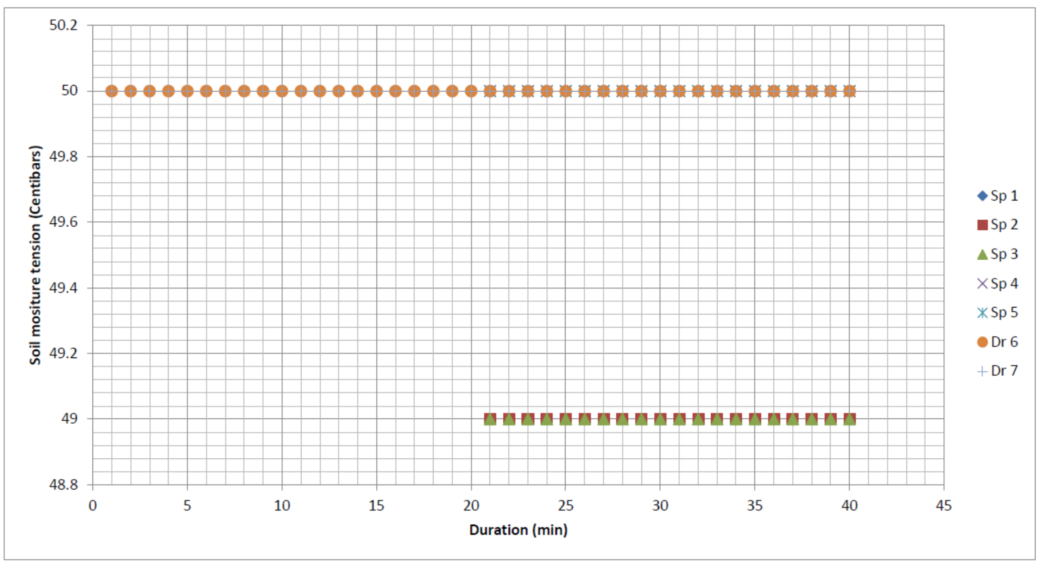


Figure 4.6 Soil moisture tension reading on August 1st, 2017

Figure 4.7 also shows sensor readings on August 15th with minimal changes compared to the previous reading. The irrigation system operated at the same duration, similar to the previous figure. On the other hand, figure 4.8 has started to show a slight change in the duration operated for the sprayer irrigation system. The 2 minutes reduction in the duration of the sprayer irrigation system is a positive indication of the effectiveness of the technology used.

Figure 4.7 to Figure **4.10** have also shown positive results especially in the turf grass with a total reduction of 5 minutes for the sprayer irrigation system. Note that the readings were always in the range of 49 – 50 Centibars, which indicates the need for irrigation at the required time. Most irrigation cycle occurred in the morning from 10:30 to 11:00.

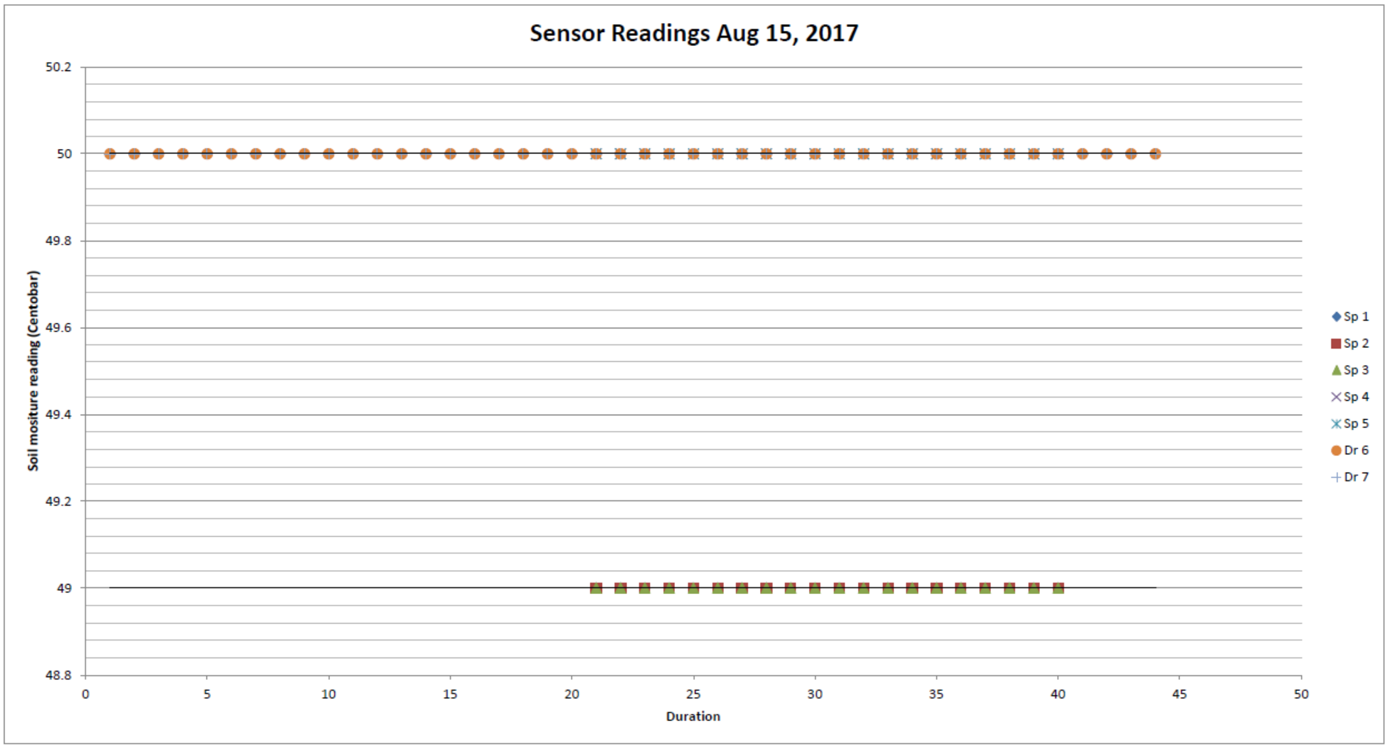


Figure 4.7 Soil moisture tension reading on August 15th

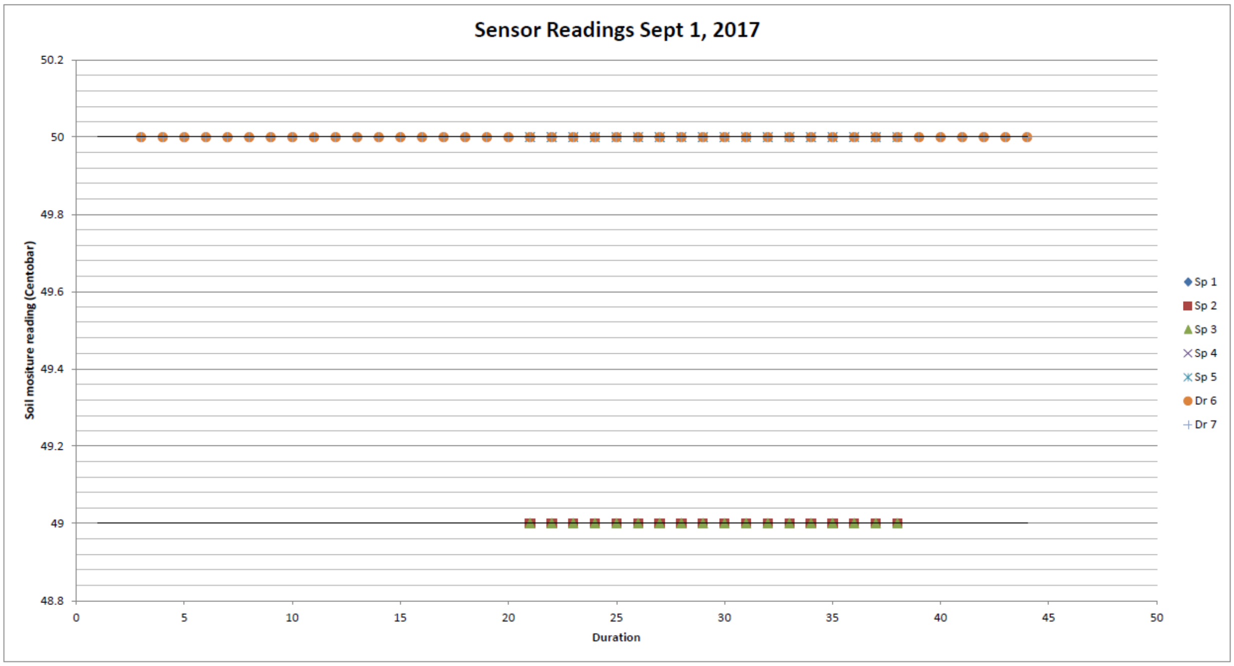


Figure 4.8 Soil moisture tension reading on Sep 1st, 2017

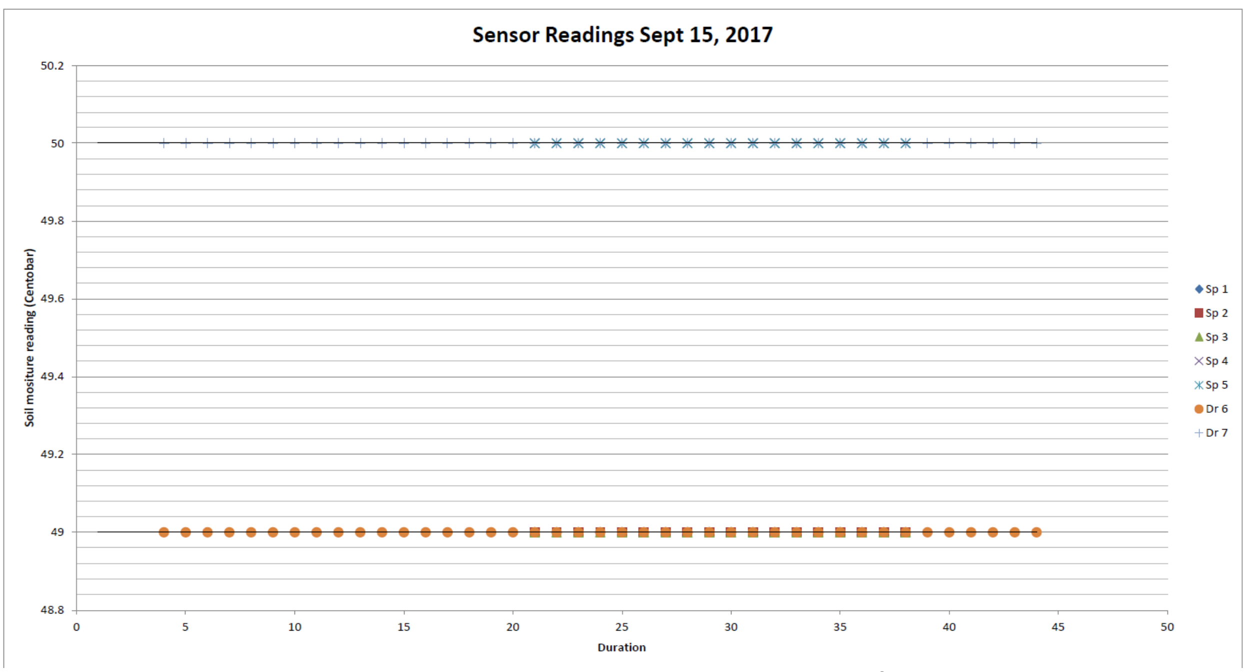


Figure 4.9 Soil moisture tension reading on Sep 15th, 2017

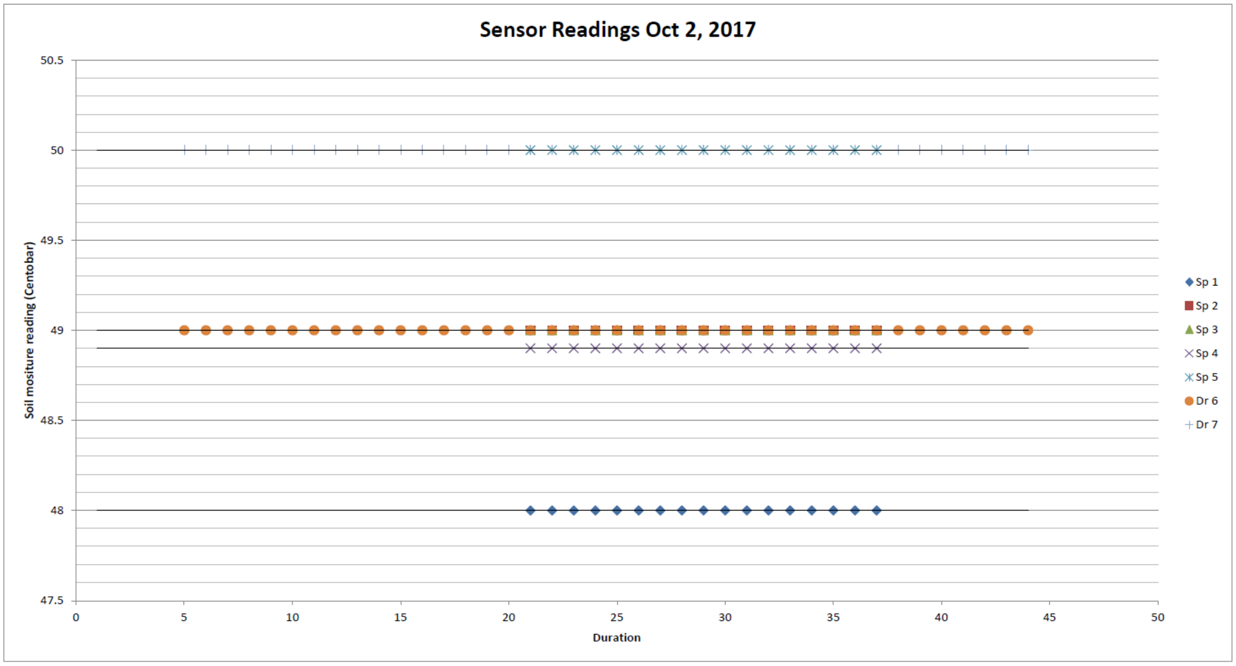


Figure 4.10 Soil moisture tension reading on Sep 15th, 2017

To assess the plantation growth of the area, numerous images of the field grass has been taken in various weeks to measure the effectiveness of soil moisture sensor in plants growth and aesthetic appearance. The assessment of the grass is based on various parameters such as color, uniformity, disease, drought stress, density and quality. Figure 4.11 shows the grass after been treated. Many spots have shown better results with greener leaves. The yellowish turf grass decreased in lots of spaces enhancing the overall appearance. The fungus disease, yet, has shown less impact with the integration of soil moisture sensor. This can be due to different factors other than the irrigation scheme, effecting the soil in which caused the disease to continue spreading.

The bougainvillea on the other hand is measured through the brightness of its flowers. **Error! Reference source not found.** shows the bougainvillea with no significant difference in the overall appearance or growth, yet more water was conserved by irrigating for shorter period and a reduction of approximately 3-4 minutes. Note that bougainvillea is a type of plants that need less water when it’s grown, and that can be the reason for the less significant impact when managing the irrigation system.

Figure 4.11 Grass growth during the field experiment

Figure 4.12 Bougainvillea irrigated by dripper after using SMS

Table 4.9 elucidates the water flow for the different nozzles used in the selected plot of the field experiment after integrating SMS. The table shows the water volume variations during the 4 months. The changes started appearing in September when the irrigation duration started to change and decrease. The significant difference was found in October in which the water volume was approximately 0.19 m^3/ min while using SIS in comparison to CIS that resulted in 0.26 m^3/ min. Moreover, using CIS continued irrigating for 20 minutes while the use of SIS resulted in 5 minutes reduction in the overall irrigation of the sprayer irrigation system.

Table 4.9 water volume calculation for 1.0 and 1.5 bar for the sprayer system – Scenario 2						
Nozzle radius	**No. of Nozzles used**	**Month**	**pressure**	**Irrigation duration**	**Water Volume**	**Water Volume (Base case Configuration)**
360° (Full circle)	36	July	1.0	20 min	7.2 m^3/ min	7.2 m^3/ min
		August	1.0	20 min	7.2 m^3/ min	7.2 m^3/ min
		September	1.5	16 min	7.36 m^3/ min	9.36 m^3/ min
		October	1.5	15 min	6.9 m^3/ min	9.36 m^3/ min
180° (Half)	24	July	1.0	20 min	2.4 m^3/min	2.4 m^3/min
		August	1.0	20 min	2.4 m^3/min	2.4 m^3/min
		September	1.5	16 min	2.3 m^3/min	2.88 m^3/min
		October	1.5	15 min	2.1 m^3/min	2.88 m^3/min
90°	4	July	1.0	20 min	0.2 m^3/ min	0.2 m^3/ min
		August	1.0	20 min	0.2 m^3/ min	0.2 m^3/ min
		September	1.5	16 min	0.20 m^3/ min	0.26 m^3/ min
		October	1.5	15 min	0.19 m^3/ min	0.26 m^3/ min

4.1.3 Discussion on the previous scenarios

The soil moisture readings that resulted from the experiment in the selected plot were very similar between the different replications. July through October 2017 was a continuous hot dry period and relatively 0% rainfall amount. Often soil moisture sensors are affected by temperature, precipitation rate, evapotranspiration (ET) and runoff. As discussed earlier, the precipitation rate was 0% during the experiment, therefore it is essential to consider the heat temperature especially in arid / semi-arid areas such as Dubai. That also includes the evaporation rate from the soil and transpiration from the vegetation and both processes can't be separated. As both transpiration and evaporation rate are affected highly by the temperature, it is essential to estimate the average temperature during the experiment. The weather during the experiment was mostly hot and dry in many days in Warsan area. Table 4.10 shows the change in average temperature from mid-July to mid-October for the entire months. The highest average temperature as shown in the table was found in August, while the lowest average was found in October.

Table 4.10 Average temperature during the experiment	
Month	**Average temperature**
July	38° C
August	38.5° C
September	36.5° C
October	33° C

The average temperature shows a decrease from July to October by 5.5% affecting the irrigation and water requirement. The irrigation schedules on scenario 1 showed that the current system is based on random patterns of irrigation, daily irrigated, taking into consideration the water requirement set for each vegetation type. The system is turned on mostly early morning to avoid any water disturbance in the pathways or to avoid water splash to the labors working, or evening when no labors on site. The irrigation system turns off by noon at the intense heat to avoid water evaporation while irrigating. In Figure 4.3, one of the pots has been overwatered in scenario 1 when irrigating via the controlled irrigation system, due to less management between the labors on site and the irrigation engineers while other pots were irrigated consistently. The controlled irrigation system used currently showed poor irrigation management that required labors on site to ensure the effectiveness of the system. On the other hand, grass disease is also another issue found previously and extended also during the experiment. This indicates a problem with either the soil, fertilizer or the roots of the grass. Yet it has not been considered for this study. The low water pressure of the nozzles in summer, especially in the month of July and August has also resulted in a negative impact when using the controlled irrigation system on the landscape and no significant impact while using SMS. Figure 4.13 shows the differences in water flow between the two systems. S1 represents the controlled irrigation system, while S2 is the smart irrigation system. The significant change was found in October with a gradual drop in the water flow. With the increase in pressure, the water flow has also increased, yet, as the operating time has decreased in scenario 2, the water flow decreased respectively.

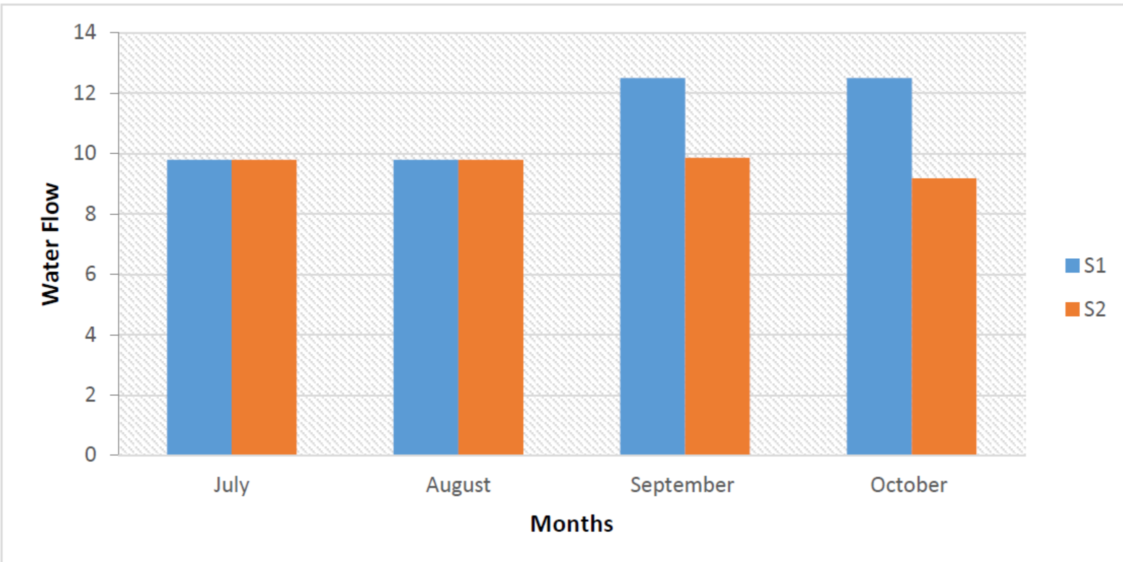


Figure 4.13 water flow of S1 (CIS) and S2 (SIS)

On scenario 2, sensor readings were very minimal and nearly similar in July and August where the temperature is between 35 **°C** to 45 **°C.** Due to an error caused by the unattached sensor to the unit, the readings in Table 4.8 taken on July 20th showed a very high number approximately 254+ CB and this is considered as an open circuit. The high temperature in July and August showed almost no change in the irrigation duration. Both systems have been operating for 20 minutes for the sprayer and 45-60 minutes for the drip irrigation. Overall, the irrigation treatment was shorter compared to the controlled irrigation system (CIS). In September the sensor readings decreased gradually, however it was still under the dry condition in which irrigation was required. Once the soil is saturated, the sensors sent signals to stop irrigating. The beginning of

October has also resulted in a positive decrease in irrigation treatment due to the foggy days experienced at the early hours in the morning and the improvement in water pressure.

To measure the effectiveness of soil moisture sensor (SMS) in managing irrigation schedules, it was also essential to monitor the scheduled irrigation cycle (SIC) on site. It is important to apply water at the right time with the right amount to ensure best management practice. During the 102 days of the field experiment, the irrigation was mostly allowed on the selected plot. Moreover, with 0% rainfall, the condition of the site is mostly dry causing no bypass in the irrigation schedule.

Figure 4.14 shows the average soil moisture tension in different time of the months in regards to the scheduled irrigation cycle (SIC). The soil moisture tension average from 0-30 is where the soil is adequately wet, as mentioned earlier in Table 4.6, and this indicates where the soil is saturated and irrigation should be bypassed. As shown in Figure 4.14, most of the sensor readings in which the irrigation system was allowed falls above the average in which the soil is in the range of irrigation frequently for this study.

No significant differences were found between both irrigation systems in terms of allowing or bypassing the irrigation cycle in the selected months of the study. Both systems were actively working daily, yet on different timings of the day with slight difference on the duration when using SIS.

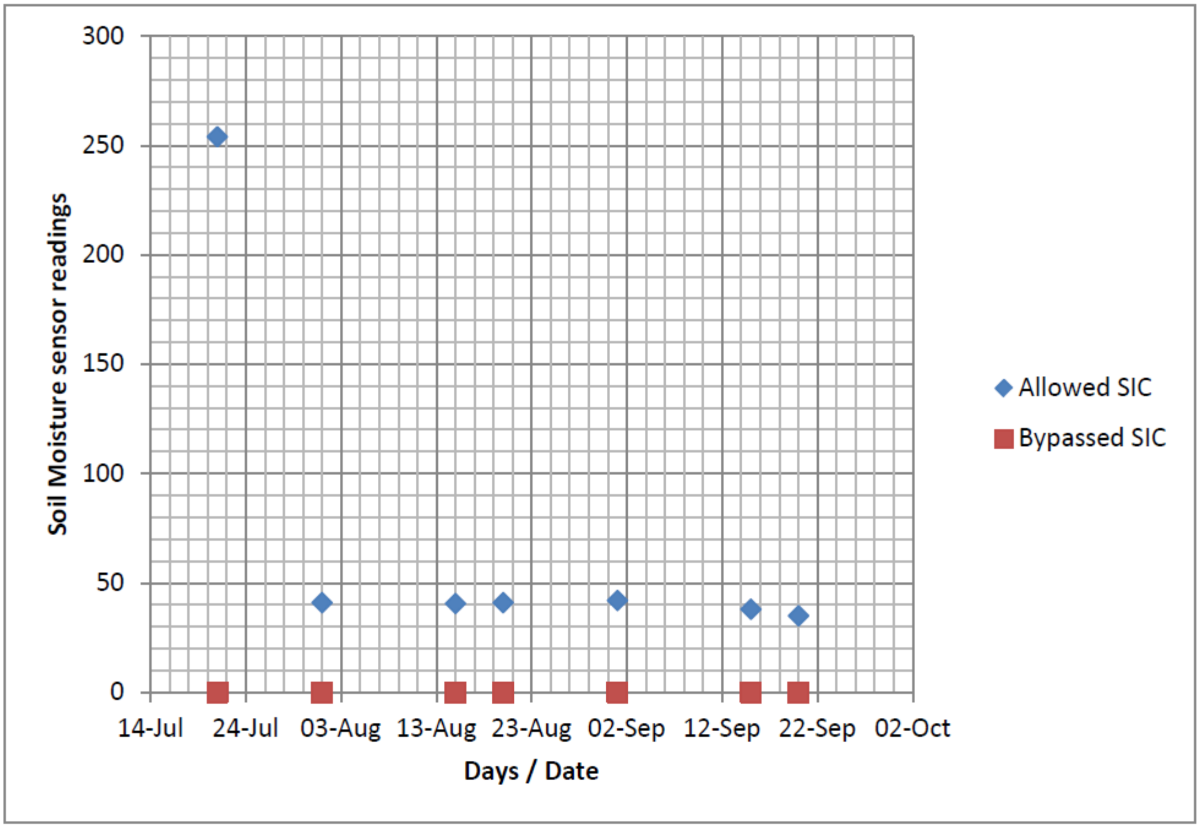


Figure 4.14 the relationship between sensor readings and scheduled irrigation cycle (SIC) during the experiment.

4.2 Irrigation management

Irrigation water was scheduled and applied for the field grass and shrubs using the existing controlled system and smart controller system via SMS. The average quantity of water applied in both techniques were monitored and recorded. The advantage of using of SMS in comparison to the controlled irrigation system is that less management required either on site or through the controller because once the soil moisture controller is set then the sensors does the management of irrigation. The required management is through computer software where the engineer is able to detect any damages or leakage in the system. The smart system provides a proper management of the exact timing and duration in which the soil is in high demand of water. Less labor is required on site for supervision. The controlled irrigation system (CIS) required 1-2 labors to ensure the system operation at the required time. On the other hand, the smart irrigation system did not require any labors on site once the system was successfully operating.

Looking at the water use efficiency (WUE) of the controlled irrigation system, the measurement is looked upon based on the time irrigated and the duration. It has been witnessed a slight change in water consumption. The value of WUE increases when measuring the saving of irrigated water and time applied. WUE for both scenarios indicates that less water is used through the smart moisture sensor which as a result more water was being saved via the effective system of smart system controllers as agreed in the previous study. Even though the difference in values of both systems is very minimal, yet, the long term use of smart system will have a bigger impact especially in the sustainable economic growth of the city. Figure 4.15 shows when both systems are working on Oct 2nd, the differences in duration and time of operation between the controlled irrigation system (CIS) and the smart irrigation system (SMS). When using CIS, the dripper was operated for 45 minutes early morning while the sprayer was operated twice, each for 10 minutes as the daily schedule. However, when using the SIS, the soil moisture sensor was also operated early morning at 10:33 am for only 15 minutes for the sprayer and 41 minutes for the drip irrigation. This is the most significant day in which the difference can be recognized in terms of irrigation duration and management.

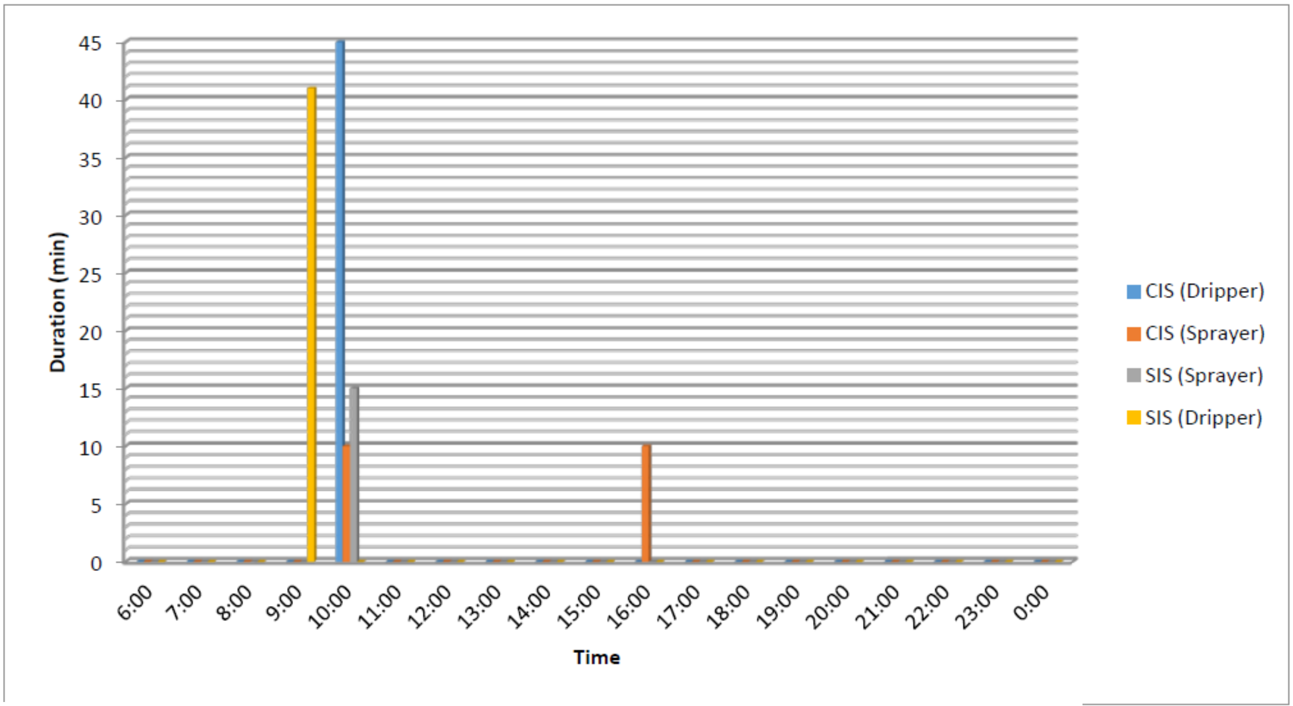


Figure 4.15 The difference in irrigation duration and time for a selected day in October.

4.3 Economic analysis

The economic analysis is done through calculating the cost estimated for the installation of the technology, the running cost, maintenance and labor if required. Moreover, this will be compared to the cost of the current irrigation practices and the operation of the existing system. Furthermore, the amount of water saved in each system will ensure a tremendous value in the economical aspect of the system. The water saved from each system plays a valuable input towards increasing the sustainability aspect of the integration of the smart system.

The economic inputs are based on the local market and the price of the equipment is in US dollars. The economic feasibility is very important in determining the acceptance of the product in the business world and whether the product is worth the investment.

Economic and technical analyses are essential in making an investment in any new product in the market. This would look into the technical changes added by the integration of soil moisture sensors into the existing irrigation system. Moreover, it would examine the facilitating of the irrigation practice before and after using sensors. Each scenario will be analyzed separately to assess its economic and technical aspects and to understand the efficiency of each system. This will determine what the best case for the current situation is.

4.3.1 Scenario 1: Base case analysis – Controlled irrigation system (CIS) via sprayer and drip

The cost of irrigation practices is changing dramatically throughout the years. With more technological and modern accessories coming up to the market, public and private sectors are integrating these technologies. Sprayer, sprinkler and dripper are the most predominant irrigation system used in Dubai, especially for grass, shrubs and seasonal flowers. Drip and sprayer both offer reasonable initial and operating cost for projects. This system has also reduced labor cost comparing to the manual irrigation by hose that is still used in small – medium projects in the region. In the selected plot in Warsan, one to two labors are required to turn the valves on and off on site from the controller and ensure the operational activity. The maintenance required for the CIS is twice seasonally to ensure no damages in the nozzles or system that might cause leakage or water runoff.

Two suppliers are mostly known for irrigation systems in the region, one is Hunter industry and the other is Rain Bird. Table 4.11 indicates the price of irrigation system and its accessories. The differences in prices between the two suppliers are very minimal, yet Dubai Municipality is mostly contracting Rain Bird, and the current irrigation system is installed by Rain Bird.

Table 4.11 Sprayer and drip irrigation systems and accessories pricing ("Rain Bird Online Store - your direct source for genuine Rain Bird sprinklers and irrigation products." 2017)		
Sr. No.	**Item**	**Price ($/piece)**
1	Sprayer head	2.50 – 6.0
2	Nozzles	1.0 – 5.0
3	Rotors	1.0 – 7.99
4	Impact sprinkler	26.0 – 300
5	Hose end sprinkler	11.0 – 23.99
6	Systems and kit	141.90
7	Parts and accessories of the sprinkler	0.33 – 20
8	Timers	Standard : 50 – 200
9	Sprinkler valves	18 – 200
10	Valves boxes	2.0 – 60.0
11	Valves Parts and accessories	50.0 – 200.0 $
12	1800 Spray Head Drip Riser Connection Kit	19.99 $
13	CNV2XBIRD - 1/2 in. Riser to 8-Port Drip Manifold Conversion Kit	23.08 $
14	Faucet Connection Kit	19.99
Total Price		366-79 – 1164.88 $

The prices can add up depending on the size of the project and the landscape requirement. More equipment's might be needed with the increase in plant variations and size. For the size of the selected plot of the experiment, the approximate cost of the irrigation systems is 500$ excluding the controller system, for both dripper and sprayer. Maintenance cost is calculated as 7 AED per m^2 for the maintenance company hired by the Municipality. The total area used for the field experiment is 60 m^2 which means 420 AED is the cost of annual maintenance for the selected plot using the controlled irrigation system. Replacement is required only when damages occur, especially for the sprinkler and sprayer head, and this occurs once or twice a year.

4.3.2 Scenario 2: Case analysis using soil moisture sensor (SMS)

The economic analysis of this scenario has to take into consideration that the previous system was currently in use and working well on site. The price of the technology varies depending on the supplier. Various companies have been offering the same technology of soil moisture sensor in the market, with differences in the controller used, the application installed and whether it is a stand-alone system or integrated to the existing irrigation system. In this field experiment, the system used is a stand-alone controller that can't be integrated to the existing irrigation system, yet another moisture sensor is available to be integrated with the existing irrigation system and is operated via a battery. A small adjustable controller is required for this system to obtain the readings and that will cost approximately 2000 AED. Table 4.12 shows the prices of SMS from various suppliers in the UAE.

Table 4.12 showing various SMS suppliers in UAE with the approximate prices of the technology

SMS supplier	SMS skit	System type	Price (US $)
Rain Bird	(1) In-ground soil moisture controller interface	Can be integrated to the existing system	100 – 572.90 $
Hunter	(1) Probe + Module	N/A	88 $
Water Gulf	(7) moisture sensor	Stand-alone system /	4,645 $

	(1) temperature Sensor Data memory card. Water graph software	Can be integrated to the stand-alone controller	
Other suppliers	Soil Moisture Sensor - 2 meter cable		39.95 $
	Soil Moisture Sensor - 5 meter cable		45.95$
	Soil Moisture Sensor - 10 meter cable		55.95 $

The table has shown a variation in the prices and this is because of the type of systems used and as mentioned earlier the type of controllers. For the selected plot, there were various costs associated with the experiment, such as replacing some of the nozzles, the smart soil moisture sensors; total of 7 sensors, and the controller. The integration of the technology for the selected plot cost around 5000$, keeping in mind that more sensors have been used to validate the results obtained. Maintenance cost and replacement is neglected at this phase, and the availability of the technology make it in a reasonable price.

4.3.3 Comparative summary of the previous cases

Comparing the previous scenarios configuration, controlled irrigation system (CIS) requires only the cost of installing the system itself. While moving towards smart irrigation system (SIS) requires additional cost to add up to the excising or the traditional system. The additional cost is required for the software used and specialized labors along with the technology itself. On the other hand, less operation is required on site for irrigation management when using SIS. This can result in reducing the number of labors. The total cost of labors is 2000 AED per labor (Alzir 2017). Note that for the selected plot, 2 labors were required per shift that means 4000 AED per shift for the selected plot will be cut cost. Yet, the SIS was easily monitored by the irrigation engineer in the office. Number of labors were reduced and their cost as well. Note that the irrigation water used is treatment water by Dubai Municipality, no DEWA water bills to include in this research study due to lack of information on the price of the treated water.

The price of the technology varies from one supplier to another yet, it has been widely available in the local market. Many private sectors and investors been using the technology in their landscape projects and positive results have been obtained. It has also been noticed that less water has been applied through the use of SMS in comparison to the existing irrigation system when comparing the duration for both; this can result in economic and environmental benefit.

The number of sensors to apply in any landscape projects depends on the variability of soil in the selected project. If the soil characteristics are consistent, the number of sensors can be reduced. For the economic analysis for the previous scenarios, the cost of the smart soil sensor is one time upfront investment which cost approximately 18,300 AED including the controller for the 60 m^2 for the number of sensors used in the selected plot. The controlled irrigation system cost approximately 5 – 10% of the overall maintenance cost which is around 3.5 - 7 AED per square meter, around 210 – 420 AED for the selected plot. Even though the cost of the technology is higher than the irrigation system itself, they are much more efficient (25% efficiency) as per the amount of water saved in the field experiment. With that said, the use of the smart irrigation system will get paid off in 2.5 years. It is also speculated that the price of the sensors would go down in the coming years as this technology is considerably new compared to the others. Furthermore, the supplier of the smart sensors are increasing in the local market as more organizations are moving towards water efficient technologies in landscape and agriculture.

Overall, this study has shown an interesting impact on how technology effects irrigation water management and scheduling. As mentioned earlier in a study by (Navarro-Hellín et al. 2016) the use of soil moisture sensors increase the accuracy in estimating the required water for plants, and therefore assist in dealing with local disturbance and water issues in the region. The findings also supported the study conducted by (Mladen Todorovic, 2016) in which the authors debated on the importance of innovative water management technologies in achieving eco-efficiency and overcoming water degradation.

To summarize the results obtained, Table 4.13 highlights the main comparison between both systems in terms of various characteristics mentioned in the table.

Table 4.13 Comparison of CIS and SIS.

Measurement	**Controlled irrigation system (CIS)**	**Smart irrigation system (SIS)**
Irrigation schedule	Fixed irrigation schedule	Based on soil moisture
Waste	Large amount of surface water wastage and runoff in some cases.	Little chance of water wastage
Plants growth	Does not consider plant productivity	Consider efficient irrigation for plant growth
Control	Mostly manually	Can be controlled manually or automatically
Software	Not available	Available
Phone App	Not available	Available for some soil sensors, depends on the supplier
Physical presence	Need physical presence	No need
Upfront investment	Average	Medium - High

Chapter 5 Conclusion and recommendation

5.1 General Conclusion

This section exhibits the general conclusion of this research study in which various methodologies were investigated and profound literature reviews looked into the problem from various parameters. The problem was also explored in different countries with similar environmental condition and climate to benchmark different variables that lead to answering the research question.

In this study, a field experiment was conducted in a hot arid region of Dubai, in Warsan nursery of Dubai Municipality. The experiment is studied closely to understand the effect of the technology, specifically IoT to the irrigation system and the landscape of the region. Various aspects were profoundly considered, such as environmental, economic and irrigation management through intense literature review prior to the field experiment.

The main aim of the research was to assess the performance of soil moisture sensor in managing the irrigation treatment and water conservation; therefore introducing new method of irrigation in response to moisture availability and climate.

The main results have been obtained from the field experiment by comparing the impact of controlled irrigation system (CIS) and the smart irrigation system (SIS). First, samples were taken from various locations at various depths to estimate the amount of moisture available in the selected plot. This helped in estimating the depth required for better results and to avoid future errors. Secondly, the site was divided into 2 plots, one using controlled irrigation system, irrigated by sprayer and dripper. And the second plot is using soil moisture sensor as a smart irrigation system. Both systems were monitored and recorded to estimate the amount of water conserved in both treatments. When using the controlled irrigation system (CIS), the scheduled valve continued irrigating at the same duration; 20 minutes for the turf grass using sprayer, and 45-60 minutes using the drip irrigation for the bougainvillea. While the use of smart moisture sensor kept decreasing the irrigation duration till 15 minutes for the sprayer and approximately 41 minutes for the dripper. Moreover, the water volume for both systems has also shown a significant difference. When using CIS the water volume calculated in October, for instance was approximately 0.26 m^3/min. Yet, in the same month, the water volume while using SIS is approximately 0.19 m^3/min. This shows 25% of the technology's effectiveness. Moreover, the plants overall appearance has shown a positive result mostly in the turf grass. The yellow spots founded at the beginning of the experiment decreased indicating the effectiveness of the sensor in operating the sprayer irrigation system. The additional cost that will result in adding the smart irrigation system will have a positive impact in the long term, especially in terms of water conservation and management. Less labor is required on site, and their cost can be reduced.

In conclusion, it can be seen that by the introduction of smart irrigation system into the irrigation practices, water consumption is lowered and monitored. Thus improving the environmental sustainable aspect of the future of landscaping and agriculture in the region. It is important for decision makers to be aware of the environmental aspects, water utilization and the impact of irrigation systems towards improving the landscaping and agriculture of Dubai. Dubai has been going through a tremendous change and transformation towards improving the quality of people's life through the use of smart technologies and IoT. The goal is to facilitate the services that will contribute towards sustainable environment and healthier lifestyle through innovative digital world.

5.2 Limitation

The field of landscape and agriculture is a vast and complex science in which is composed of various parameters to consider when measuring its factors. Conducting a research in this field can be a bit challenging especially in a limited period of time. Most of previous studies were conducted in a period of 1 -2 years to measure the impact of the technology in difference seasons as mentioned in the literature review chapter.

Furthermore, other tests were required to do further in order to achieve better results such as soil experiment at various depths in different weather condition to assess soil moisture. Moreover, soil salinity that has a major impact in plants growth and irrigation management especially in our region. Also, soil characteristics are usually known to be heterogeneous in various fields in which might impact the percentage of moisture available in the soil. In large projects, this can cause inaccurate results and extra cost to provide large number of sensors.

In respect to the challenges and constraints face in the field experiment process of this research, it should be pointed out that the methodology used is an extreme time consuming. For valuable results, the experiment was needed to be replicated for various times to ensure the results are accurate. Moreover, technical issues were also faced during the experiment in which the sensors were not at a good depth to read the available water moisture. Therefore, no irrigation was operated. A missing data was also an issue to face during this research study. Many information were collected from the mouth of various engineers working in the field of irrigation for years, yet, each had different data to share. This caused confusion on the validity and accuracy of the information collected. However, once the results were generated from the experiment, the comparison was successfully done.

5.3 Future Recommendation

As mentioned earlier, the science of landscape and agriculture are vast and rich field which this research focused on a small portion of it. Therefore, future researches can focus on various topics that will align with the futuristic plan of Dubai. These topics are:

- As Dubai is going through the concept of future accelerator, the use of shipping container to grow various crops is a new concept that will be taken place in the near future. This method accelerates the growth of plant without the use of traditional irrigation system or soil, therefore less water is consumed in a sustainable and innovative way. Moreover, LED lights are used to provide energy for the planted crops. This will enable the people of UAE in the future to plant their own crops in a shipping container next to their house.
- The impact of using smart irrigation system on reducing the amount of fertilizers used.
- Conducting a survey among decision makers in order to assess their willingness in introducing IoT systems in their irrigation system.
- Research on the level of homeowner's awareness on the impact of minimizing water consumption in their garden.
- Impact of using local plants in the UAE that consumes less water in order to achieve sustainable landscape practices.

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Appendices:

Appendix A: Soil test in Warsan Laboratory

النتائج Results					
Method	Recommended optimal range	**S. 2**	**S.1**	**Pot**	**كود العينة Sample code**
Dry weight	According to irrigation conditions	**3.5 %**	**6.59 %**	**20.7 %**	Moisture %
1:1 Extract	< 5.1 **Strongly acid**; 5.2–6.0 **moderately acid**; 6.1–6.5 **slightly acid**; 6.6–7.3 **Neutral**; 7.4–8.4 **moderately alkaline**; >8.5 **Strongly alkaline** **General optimal rang for most crops 6-8.2**				PH
Dry weight					Carbonates %
1:1 Extract	0-2 **(non saline)**; 2-4 **Low salinity**; 4-8 **Mild salinity**; 8-16 **High salinity**; >16 **Severe salinity** **General optimal rang for most crops(0-4)ms/cm**				Electrical conductivity التوصيل الكهربي
1:1 Extract					TDS الأملاح الذائبة
Khajeldahl	**Low**; **Sufficient** 0.10 -0.15 %; **Excessive**				N %
Colorimetric	**Low** <10; **sufficient** 10–20; **High** 20-40; **Excessive** >40				P(ppm)
AAS	**Low** <150 ppm*; **Sufficient** 150–250 ppm; **High** 250–800 ppm; **Excessive** >800 ppm				K(ppm)
Sufficiency or optimal rang of nutrients depends on and differs according to the crop needs					Recommendations **التوصيات**
رئيس شعبة المشاتل والمختبرات	**مسئول المختبرات**				**محلل كيميائي زراعي**

Appendix B: Site images









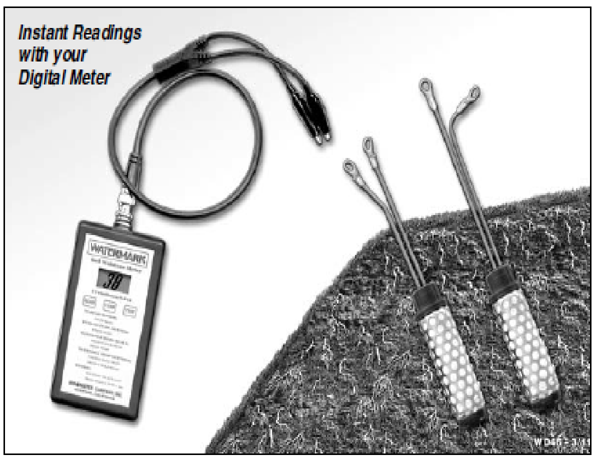
Appendix C: Sensor Manual

INSTALLATION AND OPERATING INSTRUCTIONS

WATERMARK®
Soil Moisture Meter

Instant Readings with your Digital Meter

One Meter reads all Sensors



The soil acts as a reservoir to store water between irrigations, or rainfall events, so that it is available to the crop or plants as needed for healthy growth. The purpose of using sensors to measure soil water is to give you a better understanding of how fast water is being depleted in the different areas of your field, so you can better schedule your irrigations and correctly evaluate the effectiveness of any rainfall. By reading the sensors 2-3 times between irrigations, you will gain an accurate picture of this process over time, and develop an irrigation scheduling pattern that meets your crop's "need" for water. This eliminates the guesswork, can result in water savings, lower pumping costs and eliminate excess leaching of nitrogen due to over irrigation.

SENSOR SITE SELECTION — Often more than one sensor should be placed at a given location, at varying depths. For instance, one sensor in the upper portion of the plant's effective root zone and other sensors located deeper into the root zone profile. We refer to this as a "sensing station", and it can give a better representation of the plant's uptake of water.

PLACEMENT —

Furrow or Flood Irrigation – Locate sensing station about 2/3 the way down the run, just ahead of the tail or backup water. This is the area where water penetration is usually the poorest. With tree crops, locate sensors on the southwest side of the tree (in the Northern Hemisphere) as this side gets the hot afternoon sun.

Sprinkler Irrigation – Even though the distribution is typically more uniform with sprinkler irrigation, there can be great differences in penetration and holding capacity due to soil variations, interfaces and contour. These various sites make good locations for sensor stations. With tree crops, locate sensors at the drip line of the canopy being sure that they are not obstructed from the sprinkler's distribution. With row crops, locate sensors right in the plant row.

Center Pivot Irrigation – Place sensors at 4 - 5 locations down the length of the pivot (between towers) just ahead of the "start" point. Additional locations at "hot spots" (good or poor production areas of the field) can help give a better overall view of the field. Be sure to use enough "sensing stations"; every 10 - 15 acres is a good rule of thumb.

Drip or Micro Irrigation – Sensors must be located in the wetted area. With drip emitters, this

1

is usually 12"-18" (30-45-cm) from the emitter. With micro-sprinklers, usually 24"-36" (60-90-cm) is best. Monitor often enough to get a good overall picture of the field, or irrigation "block", and consider the soil variations which exist. Keep in mind that light soils dry very quickly and heavy soils more slowly.

DEPTH — This depends on the rooting depth of your crop, but can also be affected by soil depth and texture. With shallow rooted vegetable crops, one depth may be adequate (root system less than 12"[30 cm]). With deeper rooted row crops (small grains, vines and trees) you need to measure soil moisture in at least two depths. With deep well-drained soils, crops will generally root deeper – if moisture is available. With coarse, shallow or layered soils, root systems may be limited in depth. In general, sensors must be located in the effective root system of the crop. Guidelines on proper depths for specific crops and conditions can be obtained from IRROMETER as well as your local farm advisor.

***Note** — Our recommendation for anyone using sensors for the first time is to use an adequate number of "stations" over a smaller area to begin with, to get an accurate picture. Then read them regularly over the season to learn the patterns which normally develop.*

INSTALLATION — Soak the sensors overnight in irrigation water. Always install a wet sensor. If time permits, wet the sensor for 30 minutes in the morning and let dry until evening, wet for 30 minutes, let dry overnight, wet again for 30 minutes the next morning and let dry again until evening. Soak over the next night and install WET. This will improve the sensor response in the first few irrigations.

Make a sensor access hole to the desired depth with an IRROMETER installing tool or a 7/8" (22 mm) O.D. rod. Fill the hole with water and push the sensor down into the hole so it "bottoms out". A length of 1/2" Class 315 PVC or 3/4" CPVC pipe will fit snugly over the sensor's collar and can be used to push in the sensor. A good snug fit in the soil is important. This PVC can be solvent welded to the sensor collar with a PVC/ABS cement (IPS Weld-On #795 or equal).

If the PVC pipe is not left on the sensor, then backfill the hole so the sensor is buried (see Fig. 1). The sensor's wires can easily be staked up for easy access. If PVC is left on, then compact the soil around the surface to seal off the hole (see Fig. 2). The PVC acts as a conduit for the sensor's wires. Be sure to cap off or tape the top of the pipe, so surface water will not infiltrate to the sensor and give a false reading. Drill a small hole to allow any trapped water to drain away. Label each pair of sensor wires to indicate the measurement depth.

For very coarse or gravelly soils, an oversized hole (1" – 1.25" [25 mm - 32 mm]) may be needed to prevent abrasion damage to the sensor membrane. In this case, auger a hole to the desired depth and make a thick slurry with the soil and some water. Fill the hole with this slurry and then install the sensor. This will "grout in" the sensor to ensure a snug fit.

Another method of installing sensors in difficult gravelly soils, or at deeper settings is to use a "stepped" installing tool (see Fig. 3). This makes an oversized hole for the upper portion and an exact size hole

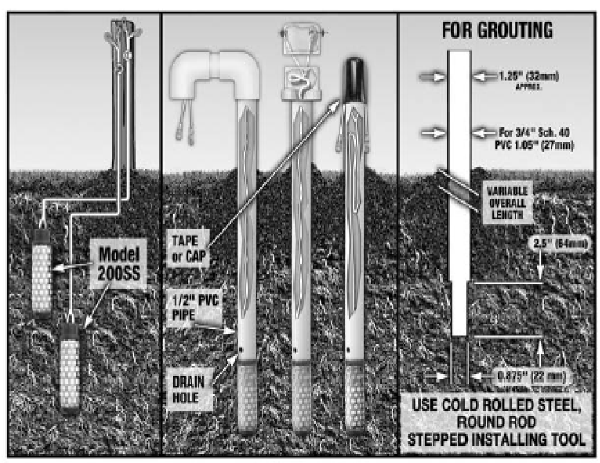


Figure 1 Figure 2 Figure 3

2

(sensor is 7/8" [22 mm] O.D.) for the lower portion where the sensor is located. The hole must be carefully backfilled and tamped down to prevent air pockets, which could allow water to channel down to the sensor.

If sensors are removed, clean and dry them. They can be stored indefinitely in a clean, dry location. Always soak before re-installation.

WIRING SENSORS — If additional wire length is needed, simply splice the additional wire to the sensors wire leads. This wire splice must be fully waterproof (3M Scotchpak, Duraseal heat shrink splice connector, or equal). This wire can be extended up to 1000' (305 m) with #18 gauge (.8 mm²) UF wire. Avoid long wire runs near power cables. The transient currents can affect the small current used by the WATERMARK meter. This can be checked by reading the sensors at both ends of the wire run.

WATERMARK METER – 30 KTCD-NL *(Green Case)* **—**

Attach the meter's leads to the sensor's wires with the alligator clips, being sure the separate leads are not touching each other.

Press "READ" to wake up the meter, you will see "– –" in the display. The meter will stay awake for 5 seconds (to keep meter awake for 60 seconds, press "TEMP" before "– –" goes away).

Press "READ" again while "– –" is in the display. The soil moisture reading will immediately appear in the display and remain for 60 seconds while you record it. The meter will then turn itself off.

When taking readings, the soil temperature adjustment should be set for the actual soil temperature at the depth of sensor placement. A soil thermometer can be used to obtain this value. Soil temperature does not change drastically during the season, so usually a measurement at the beginning of the season is sufficient. If the temperature value is not changed, the trend of the readings will not be affected, only the absolute value will. Analysis of the trend is of primary importance to see how rapidly the soil is drying. This setting compensates for seasonal variations in soil temperature, which can go from the 60°F (16°C) range in the spring into the 80°F (27°C) range in the summer. This variation in soil temperature can affect the readings by 1% per degree Fahrenheit, so the temperature compensation greatly improves the accuracy of your readings.

To check the temperature settings, press "TEMP". The temperature setting and the scale (°F or °C) will alternate in the display.

To change the temperature scale, press and hold "READ", then alternately press "TEMP" until the desired scale (°F or °C) appears in the display and then release READ button.

To change the temperature setting, press and hold "TEMP" then press "READ" to change the setting. The temperature setting will begin to increase until the desired setting appears in the display. The full scale of temperature setting is 41°F (5°C) to 105°F (40°C). Once the temperature scrolls up to 105°F, it will go to 41°F and begin scrolling upwards again. You can reverse the direction of scrolling at any time by releasing the "READ" button and depressing it again (while continuing to hold "TEMP" down).

The temperature settings you programmed in will remain until you change them. The meter comes with a default setting of 75°F (24°C).

The meter has a built-in test function. To test the meter for accuracy, with the temperature setting at 75°F (24°C), press and hold "READ" and "TEST" simultaneously. A reading of between 95 and 105 should appear in the display. This reading indicates the meter is functioning properly. **During test, make sure cable leads are not touching or hooked to a sensor.**

This digital meter has a full range of 0 to 199 centibars built in.

The digital meter utilizes solid state electronics and is sensitive to extreme heat. Do not store the meter on the dashboard of your vehicle or any other very hot location. Replace battery with a good quality 9V alkaline battery at least once each year. The meter has a low battery indicator and the battery should be replaced whenever "LO" appears in the display.

DATA LOGGING DEVICES — If sensors are to be read by a data logging device, it must be compatible with WATERMARK soil moisture sensors. Please contact IRROMETER for compatibility information. Many data loggers are compatible with WATERMARK sensors and a current list can be obtained by calling **(951) 689-1701** or e-mailing **techsupport@IRROMETER.com**. If compatibility is not verified, inaccurate readings could be obtained and sensor longevity could be affected.

Modified WATERMARK sensors, with a linear voltage output, are available for use with data loggers that are not directly compatible. Always verify the reading by comparing to that obtained with the hand-held meter.

***Note** – Our old style 30 KTCD meters, with the tan colored case, are still fully usable. They operate a bit differently than the newer 30 KTCD-NL, with the green case, but we will still offer repair and upgrade services for a number of years.*

TROUBLESHOOTING — Every now and then you may encounter a situation where the sensor doesn't seem to be working properly. Please follow the steps below to determine if the equipment is functioning correctly or to determine if the field condition needs modification.

1. First check the meter.

A. Is the battery O.K.? It should be replaced at least once a year, more often with frequent use. Check to be sure the battery contacts are clean and tight on the battery terminals.

B. Follow the test procedure on the meter.

C. If there has been some wire damage to the meter's leads, it could malfunction. To check this, clip the leads to each other and push the "READ" button. The number 0 should appear in the display. If it does, then the leads are O.K. Moving the wire leads while reading will help to show if there is an intermittent wire connection problem. Holding the "READ" button down will result in continuous reading, while you move the wires. Replacement cables are available as a spare part.

D. The LCD display on the meter has three digits. If you see only partial digits, the LCD may be suspect and should be returned for examination and/or repair.

2. Then check the sensor.

A. With a sensor submerged in water, your meter reading should be from 0 to 5. If the sensor passes this test, go on to step B.

B. Let the sensor air dry for 30 to 48 hours. Depending on ambient temperature, humidity and air movement, you should see the reading go right up from zero to 150 or higher – even off scale (LCD will read 199 when it reaches 199 cb or more)

C. Put the sensor back in water with the meter leads attached. The reading should return to between zero and 5 within 2 minutes. If the sensor passes these tests, it is O.K.

3. Next check the field conditions.

A. The sensor does not have a snug fit in the soil. This usually happens when an oversized access hole has been used and the backfilling of the area is not complete. Re-install the sensor nearby, carefully backfilling the access hole.

B. Sensor is not in an active portion of the root system, or the irrigation is not reaching the sensor area. This may happen if the sensor is sitting on top of a rock, or below a hardpan, which may impede water movement. Re-installing the sensor should solve the problem.

C. If the soil dries out to the point where you are seeing readings higher than 80 centibars, the contact between the sensor and the soil can be lost. The soil starts to shrink away from the sensor. If the irrigation only partially re-wets the soil (soil suction above 40 centibars), it will not fully re-wet the sensor and may result in continued high readings. Fully rewetting the soil and sensor usually restores the contact. This is most often seen on heavier soils during peak crop water demand periods when irrigation may not be sufficient. Plotting your readings on a chart provides the best indication of this type of behavior.

MANAGEMENT — The key element in proper soil moisture measurement is the operator. Taking the time to properly read your sensors will give you a vivid picture of what is happening with the soil moisture down in the root system of your crop. Usually 2–3 readings between irrigations is sufficient. Plotting these readings onto a chart for each sensing station creates soil moisture curves, which show you exactly how quickly (or slowly) your soil moisture is being depleted.

Just as a thermostat in your home guides you in maintaining the desired temperature, the WATERMARK readings guide you in maintaining desired soil moisture content. And just as you need to know when and how much fuel is needed to keep a safe reserve on hand to meet varying climatic conditions, it is necessary to know when and how much to irrigate to maintain soil moisture content within the desired range. This requires planning irrigations in advance, based on seasonal use in the past.

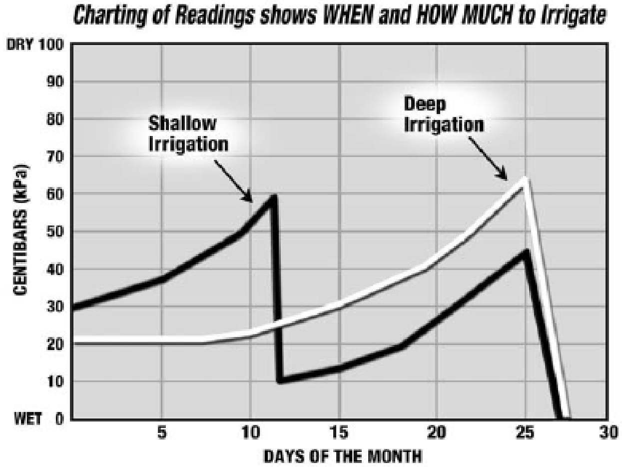
The WATERMARK charts provide the simplest method of keeping records for this purpose. Special pocket size chart forms are included with each WATERMARK meter. Readings are plotted directly in the field. The resulting curves give a picture of the rapidly fluctuating soil moisture conditions throughout the root zone, in each section, that can be visualized in no other way. "Rate of change" may be the best indicator of WHEN to irrigate. That is, if the reading increases 10-15 centibars (kPa) in just a few days, the soil is drying rapidly. Thus the charts provide a complete original record with an absolute minimum of clerical work. Projecting the seasonal curves for each section makes it easy for the grower, or executive in charge of larger operations, to plan irrigations in advance. Reference to past charts makes it possible to maintain the most desirable soil moisture content in each section year after year. The charts are a very important factor in WATERMARK irrigation control, and it is strongly recommended that they be kept up to date. The charts are also useful to keep rainfall information, fertilizer applications and unusual weather conditions posted with moisture readings for future reference.

Use the following readings as a general guideline:

- 0 – 10 centibars = Saturated soil
- 10 – 30 centibars = Soil is adequately wet
  (except coarse sands, which are beginning to lose water)
- 30 – 60 centibars = Usual range for irrigation (most soils)
- 60 – 100 centibars = Usual range for irrigation in heavy clay soils
- 100 – 200 centibars = Soil is becoming dangerously dry for maximum production. Proceed with caution!

Your own situation may be unique because of differences in crop, soils and climate. Perhaps the most important soil moisture reading is the difference between today's reading and that of 3 – 5 days ago. That is to say, how quickly is the reading going up? A slow increase means the soil is drying out slowly. But a big jump means the soil is losing water very rapidly. This tells you **WHEN** to irrigate (see chart below).

Charting of Readings shows WHEN and HOW MUCH to Irrigate



By using sensors at two or more depths in the root system, you soon learn **HOW MUCH** water to apply. If the shallow sensor shows a rapidly increasing reading, but the deep sensor shows adequate moisture, you can run a short irrigation cycle as you only need to replenish the shallow root profile. If the deep sensor also shows a dry condition, then a longer irrigation cycle is needed to fully re-wet the entire root zone. The readings you take after an irrigation or rainfall event will show you exactly how effective that water application really was.

Your own experience and management will soon point you in the proper direction. You will be practicing "irrigation to need" with the expected positive results that come from any good management program.

INTERPRETATION — Wetting soil might be compared to wetting a sponge. The sponge will hold only so much water and will absorb that water in a few seconds. Holding it under the faucet for an hour will neither cause it to absorb more water nor hold that water longer. Various soils take longer to absorb water but the same principle applies. Any excess water applied is wasted by deep percolation or run-off. By far the greatest waste is usually due to percolation because this loss is not visible.

Probably the greatest saving in water affected by WATERMARK control results from saving unnecessary and excessively heavy irrigations. Most growers find that they had previously been holding certain sections "under the faucet" far longer than necessary at times, while other sections may have been short of water. Correcting these conditions – using water where, when and in the amount needed – often results in surprisingly large net savings of water at the end of the year. However, it is not unusual to find that more water is required, in some sections, during some periods.

In soils where there is a very slow rate of infiltration, seepage to the level of the "deep" sensor may take two or three days. The drop in readings will be delayed accordingly. Under these conditions, a substantial saving in water can be effected by applying half the water used previously and waiting to see whether this brings readings on the "deep" sensor down to field capacity, instead of continuing to irrigate right up to the time that penetration is registered. Experience over two or three irrigation cycles will indicate the minimum amount of water required to ensure penetration to the lower root zone. Also, there can be water savings if irrigations start while there is still considerable moisture in the soil. Water penetrates moist soil much more rapidly than dry soil, so less water is required to infiltrate to the lower root zone.

It is usually found that readings on the "shallow" sensor rise much faster than on the "deep" sensor, due to the higher plant use of water in the feeder root zone and to surface evaporation. If readings on the "deep" sensor indicate that there is adequate soil moisture at this level, water is saved by applying only enough water to bring down the readings on the "shallow" sensors. Under some conditions, water is saved by irrigating alternate furrows, during at least part of the irrigation season. In hillside plantings, sensors placed at upper and lower locations frequently indicate unsuspected run-off or subsoil drainage. Radical reduction or even discontinuance of irrigations in the lower sections during some periods often results in material saving in water and at the same time maintains better soil moisture content for crop growth.

In soils containing rock or gravel, frequent soil sampling is often either impractical or the cost is prohibitive, yet these are the soils where irrigation control is needed most. They dry out quickly in hot weather and to ensure adequate moisture, much water is often wasted to deep percolation by "guesswork" irrigation. Charting WATERMARK readings frequently – even daily – often results in material water savings and in better soil moisture conditions for plant growth.

In many cases, the value of WATERMARK control goes far beyond cash savings on the monthly water bill. It makes a limited supply of water go farther and thus saves the investment required for developing new sources of supply.

WARRANTY — The IRROMETER COMPANY warrants its products against defective workmanship or materials under normal use for one year from date of purchase. Defective parts will be replaced at no charge for either labor or parts if returned to the manufacturer during the warranty period. The seller's or manufacturer's only obligation shall be to replace the defective part and neither seller nor manufacturer shall be liable for any injury, loss or damage, direct or consequential, arising out of the use of or inability to use the product. This warranty does not protect against abuse, shipping damage, neglect, tampering or vandalism, freezing or other damage whether intentionally or inadvertently caused by the user.

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IRROMETER®

P.O. Box 2424, Riverside, CA 92516
951-689-1701 • FAX 951-689-3706
techsupport@irrometer.com
www.IRROMETER.com

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