The Effects of Different Faucet Aerators on Bacterial Growth and Water Quality

تأثير اجهزة ترشيد المياه على نمو البكتيريا والتي ممكن ان تؤثر على جودة المياه

By

Mahmoud Fathi Bader

Student Id # 90041

Dissertation Submitted in Partial Fulfillment of

M Sc Sustainable Design of the Built Environment.

Faculty of Engineering & IT

Dissertation Supervisor

Prof. Bassam Abu Hijleh

April-2011

DISSERTATION RELEASE FORM

Student Name	Student ID	Programme	Date
Mahmoud Fathi Bader	90041	SDBE	

Title:
The Effect of different Faucet Aerators on Bacterial Growth and Water Quality

I warrant that the content of this dissertation is the direct result of my own work and that any use made in it of published or unpublished copyright material falls within the limits permitted by international copyright conventions.

I understand that one copy of my dissertation will be deposited in the University Library for permanent retention.

I hereby agree that the material mentioned above for which I am author and copyright holder may be copied and distributed by The British University in Dubai for the purposes of research, private study or education and that The British University in Dubai may recover from purchasers the costs incurred in such copying and distribution, where appropriate.

I understand that The British University in Dubai may make that copy available in digital format if appropriate.

I understand that I may apply to the University to retain the right to withhold or to restrict access to my dissertation for a period which shall not normally exceed four calendar years from the congregation at which the degree is conferred, the length of the period to be specified in the application, together with the precise reasons for making that application.

Signature

Abstract

Sustainable innovations aimed at protecting future generations from the effects of the global warming in addition to preserving precious natural resources such as water. Water conservation is one of the green building features, which may be achieved by using appropriate water saving plumbing fixtures like faucet aerators. Although benefit may be achieved by using such fixtures, there are also negative side effects to their use.

This study was conducted in Dubai International Academic City (DIAC), to investigate the consequences of using different faucet aerators on bacterial re-growth which may compromise the quality of the water; and to check the deterioration of the efficiency of the aerators over the time. The study is based on experimental method. Four types of faucet aerators were used, and monitored every four weeks over a six month period. 120 water samples were collected from 16 faucet aerators, and there were also 3 control points which were under three different water pressures. The water tank was also tested. A Heterotrophic Plate count was used since it is a common indicator for the monitoring of microbiological water quality in distribution systems. The samples were tested in Dubai Municipality Central Laboratory. The water flow rates, pH and temperatures were measured in the field.

The results revealed that, from cycle one to cycle four, the HPC bacteria concentration in the water tank exceeded the threshold level of 500 cfu/ml. Although the HPC concentration in the water tank dropped to a

level below 500 cfu/ml due to treatment from the main source, the HPC concentrations in the faucet aerators remained high.

The study concluded that, water pressure less than 2.5 water bar has potential to enhance the growth of bacteria in the aerators. Furthermore, the aerators saved 20% to 80% of the water and that depended on the aerator types as well as the water pressure. Finally the research recommends that, a three month periodic maintenance for the aerators might avoid the accumulation of sediments, which were the main contributor to bacterial growth.

ملخص:

الابتكارات المستدامة تهدف إلى حماية الأجيال المقبلة من آثار ظاهرة الاحتباس الحراري ، بالإضافة إلى الحفاظ على الموارد الطبيعية الثمينة مثل الماء. المحافظة على المياه هي واحدة من ميزات المباني الخضراء ، وهو ما يمكن تحقيقه عن طريق استخدام اجهزة ترشيد المياه (ايريتور). على الرغم من تحقق ايجابيات من استخدام مثل هذه الاجهزة الا انه قد تنتج جوانب سلبية على الصعيد الاخر وهذا ما تحاول هذه الدراسة استكشافه.

اجريت هذه الدراسة في مدينة دبي الأكاديمية العالمية لمعرفة عواقب استخدام أجهزة ترشيد المياه على نمو الجراثيم وبالتالي التاثير على جودة المياه، وأيضا للتحقق من تناقص كفاءة هذه الادوات مع مرور الوقت. وتعتمد الدراسة على التجربة حيث استمرت الدراسة لمدة ستة أشهر و تم جمع 120 عينة مياه من الصنابير المثبت عليها عدد 16 ايريتور و 3 صنابير كنقاط مراقبة وخزان المياه الرئيسي مع الاخذ بعين الاعتبار تنوع ضغط المياه. تم استخدام فحص هيترو تروفيك كاونت كمؤشر لرصد تركيز البكتيريا في نظام التوزي حيث تم اختبار العينات في مختبر بلدية دبي المركزي. كما تم قياس معدلات تدفق المياه بالاضافة لمعامل حموضة المياه ودرجة حرارة المياه والهواء في الموقع.

وكشفت النتائج أنه في الفترة من دورة رقم واحد لدورة رقم أربعه ان تركيز البكتيريا كانت عالية في خزان المياه وانها تجاوزت الحد المسموح به وهو 500 مستعمرة بكتيرة في كل مل. وعلى الرغم من ان هذا التركيز قد انخفض بعد الدورة الخامسة الا انه لم ينخفض داخل شبكة المياه الداخليه للمبنى بما فيه الايريتور وخلصت الدراسة إلى أن ضغط الماء اقل من 2.5 بار لديه امكانية لتعزيز نمو البكتيريا في الايريتور .
وعلاوة على ذلك ، فان توفير المياه تراوح ما بين 20% الى 80% وذلك حسب نوع الايريتور وضغط المياه. وأخيرا أوصت الدراسة ان الصيانة الدورية كل ثلاثة أشهر قد تؤدي الى تجنب تراكم الترسبات التي كانت العامل الرئيسي لنمو البكتيريا.

Dedication

This research is dedicated to my beloved parents (Fathi, and Ghalia), wife Refqa and children (Sara and Ahmed.)

Acknowledgment

First and foremost, I wish to thank my supervisor Prof. Bassam Abu Hijleh for encouraging and inspiring me to complete my dissertation on time. Furthermore, I would like to thank The British University in Dubai for their partial financial support for this research.

Secondly this dissertation would not have been possible without DIAC management's support especially George Varghese and Mahmoud Nasr. I would like aslo to thank Iyad Sabbagh and Babu Chancheri from EDAMA. Many thanks should also go to Rachid Lasfer from DEWA for his help in providing part of aerators which were used in the experiment.

I am grateful too for the advice of Dubai Municipality central laboratory epically Aisha Ibrahim, for cooperation during the tests.

Many thanks for Ms Mary Mayall for here assistance in reviewing the language of the text.

This thesis would not have been possible without my wife's support; She has shared my many challenges during this dissertation work. Finally, I am grateful to my many of friends for supporting me to achieve my goal particularly Ziad Alasad and Farah Yaseen.

Table of Contents

Abstract…………………………………………………………………………….………….........…….i

Dedication ……………………………………..…………………….………………….………….iv

Acknowledgements ..………………...…………………………………………….……..…..v

List of Tables……………………………………………………………...………..…………..ix

List of Figures …………………………………………………………………………….……xi

Nomenclatures…………………………………………………………..…………………….……xiv

1. Introduction
   - 1.1 worldwide water scarcity and climate change………………………..……..…1
   - 1.2 Domestic water quantity and health..………..…………………….….………..3
   - 1.3 The development of water resources in Dubai …………………………..…….4
   - 1.4 Water consumption in the buildings……………………………….………….6
   - 1.5 Sustainability in U.A.E …………………….…………………….….….….8
   - 1.6 Side effects of using aerators …..……………………..…………..….…...…10
   - 1.7 Test for water quality evaluation………………………..……………………12
   - 1.8 Rational for the research …………………………………………………….12

1.9 Structure of Dissertation
……………………..…………………………….…...13

2. Literature Review
2.1 Needs for water conservation
……….….……….……………..……....…14
2.2 Techniques of Indoor Water Saving
…………………………….….….………15
2.2.1 Alarming Visual Display Monitors
……………………………………...…16
2.2.2 Low Flow
Fixtures……………………………………………………….17
A. High Efficiency
Toilets……………………………………………….……17
B. Showerheads………………………………………………………….………..
..18
C. Dry
Urinals………………………………………………….....………...18
D. Faucets
……………………………………………………………………....19
2.2.3 On site Gray Water Recycling
…………………………………………..21
2.3 Principle Function of the Faucets Aerator
…………………………..….…...21
2.4 The Health Issue related to Potable
Water……………………………..……..22
2.5 Heterotrophic bacteria
…..………………………………..….…...……….…24
2.6 Pathogens in Drinking
Water……………………………………………...…27
2-7 Factors Enhance the Growth of Microbiological in the Water Distribution
System..28
2.7.1 Water Temperature
…………………………………………...….……..28
2.7.2 Plumbing
Materials……………………………………...……...……29

2.7.3 Water flow Velocity
…………………………………...……….……….31
2.7.4 Biodegradable Organic Material
……………………………………….…....32
2.7.5
pH……………………………………………………………..…………...32
2.7. 6 Existence of Disinfectant Residual
…………………...………...………32
2-8 Aims and Objectives of the
study…………………………………….…………..….33

3. Methodology
3.1 Previous Methods ….
………….…..……..…….…..…………...…………………36
3.2 Selection of the Research Method
…………….…….…………………….……..42
3.3 Aerators used In the current Experiment
………….……………………………43
3.3.1 RST Long Life Aerator
(R)……………………….……………………..43
3.3.2 Neoperl
(N)…………………………………………………………………44
3.3.3 Kistenmacher
(K)……………………………….....…………………….45
3.3.4 PCA spray
(P)…………………………………………..……………..46
3.4 Description of DIAC Washrooms
……………………………………………..47
3.5 Experiment Procedures
…………………………………………………………48
3.6 Ethical issues
……………………………………….………………………..53
3.7 Limitations of the study
……………………………………………………...54

4. Results
4.1 Introduction ……………..…..……….……………...……………………………56
4.2 HPC concentration in different types of aerators …………………………..….56
4.3 HPC in faucets under different water pressures…………………………………62
4.3.1 HPC concentrations in Faucets under 2 Bar water pressure ……………….62
4.3.2 HPC concentrations in Faucets under 2.5 bar water pressure…………….….63
4.3.3 HPC concentrations in Faucets under 1.5 water pressure …………………65
4.4 Percentage of HPC of aerators under different water pressure relative to HPC in DIAC tank 68
4.5 Water parameters from Faucets under different water pressure………………..73
4.6 Water Flow rates from faucets under different water pressure 75

5. Discussion... ..84

6. Conclusion and Recommendation
6.1 Conclusion ……... ………..……….……………...………………………..…..89
6.2 Recommendation 92

References.. ..94
Appendix A Photos of DIAC plumbing Material in DIAC…………………………105
Appendix B Sample of Dubai Municipality laboratory test report …………………108

List of Tables
Page

Table 1.1 Possible effect of climate change on water resources. (Mihelcic and Zimmerman 2010)..2

Table 1.2 Typical water uses in the U.K(Sustainable building Design Manual 2004). .7

Table 2.1 Energy consumed for water production (Harvey 2006)……………..…..15

Table 2.2 Water Flow Rate for Different Fixtures according to DEWA (DEWA 2010)……………………………………………………………………………….16

Table 2.3 HPC bacterial in Potable Water (Allen 2004)……………………….……..24

Table 2.4 Sources of water contamination (Gray 2008) …………………………...27

Table 4.1 HPC concentration in aerators type P…………………………………….57

Table 4.2 HPC concentration in aerators type N………………………..…..……58

Table 4.3 HPC concentration in aerators type R…………………………….….…..59

Table 4.4 HPC concentration in aerators type K………………………………...….61

Table 4.5 HPC concentration in aerators under 2 bar water pressure……………......63

Table 4.6 HPC concentration in faucets under 2.5 bar water pressure …………..…64

Table 4.7 HPC concentration in faucets under 1.5 bar water pressure……………..65

Table 4.8 HPC concentration in the control points and water tank…………………67

Table 4.9 Percentage of HPC in aerators under 2 bar respect to HPC concentration in the tank…………………………………………………………….………...……68

Table 4.10 Percentage of HPC in aerators under 2.5 bar respect to HPC concentration in the tank………………………………………………..………………………..70

Table 4.11 Percentage of HPC in aerators under 1.5 bar respect to HPC concentration in the tank ………………………………………………………………………………..71

Table 4.12 HPC difference between the aerators under different water pressure and the tank
……………………………………………………………………………..…………..73

Table 4.13 Parameters for water in different water pressure and water tank
……..…74

Table 4.14 Water flow rate (L/min) from different type of aerators under 2 bar water pressure
…………………………………………………………………………...…..75

Table 4.15 Percentage of water flow rate relative to control point under 2 bar water pressure…………………………………………………………………………..……
…77

Table 4.16 Water flow rate (L/min) from different type of aerators under 2.5 bar water pressure
……………………………………………………………………….…………78

Table 4.17 Percentage of water flow rate relative to control point under 2.5 bar water
pressure…………………………………………………………………….…………
.79

Table 4.18 Water flow rate (L/min) from different type of aerators under 1.5 bar water pressure
……………………………………………………………………………………81

Table 4.19 Percentage of water flow rate relative to control point under 1.5 bar water pressure
……………………………………………………………………………………82

List of Figures
Page

Figure 1.1 Water consumption in different sectors in Dubai (DEWA) 2009…….. 5

Figure 2.1 Shower Monitor. (waiTEK 2009)…………………………………...….16

Figure 2.2 Showerhead (EPA 2010)………………………………………….…18

Figure 2.3 Trap with floating sealing liquid (Demirize 2006)…………….…….……19

Figure 2.4 Mechanical Working Traps. (Demirize 2006)……………………………19

Figure 2.5 Self closing taps (Prestomat2000 2011) ...…………………………...…..20

Figure 2.6 Faucet Aerator (Environment Agency Abu-Dhabi 2011)……….…….21

Figure 2.7 Aerator parts (Neoperl 2010)……………………………………………….22

Figure 3.1 Aerator type R…………………………………………………………44

Figure 3.2 Aerator type N…………………………………………………………45

Figure 3.3 Aerator type K…………………………………………………………46

Figure 3.4 Aerator type P…………………………………………...…………..47

Figure 3.5 Pressure Compensating Aerator ………………………………………47

Figure 3.6 Tools used in Field Measurements……………………………………….50

Figure 3.7 Suitable working environment in D.M lab for HPC test………..……….52

Figure 3.8 Colony Counter…………………………………………………….…….53

Figure 4.1 HPC concentrations in aerators type P………………………………..…..57

Figure 4.2 HPC concentration in aerator type N……………………………..………59

Figure 4.3 HPC concentrations in aerators type R……………………………..…60

Figure 4.4 HPC concentrations in aerators type K…………………………..……….61

Figure 4.5 Average HPC concentrations in aerators, control point under 2 Bar water pressure and the water tank……………………………….…….……………………..63

Figure 4.6 Average HPC concentration in aerators and control point under 2.5 Bar water pressure and the water tank……………………………………………..……64

Figure 4.7 Average HPC concentrations in aerators, control point under 1.5 Bar water pressure and the water tank……………………………………..………………66

Fig 4.8 HPC concentrations in the control points and the water tank………..….67

Figure 4.9 Percentage of HPC in aerators under 2 bar respect to HPC concentration in the tank……………………………………………………………………………...…69

Figure 4.10 Percentage of HPC in aerators under 2.5 bar respect to HPC concentration in the tank……………………………………………………………………………..…….70

Figure 4.11 Percentage of HPC in aerators under 1.5 bar respect to HPC concentration in the tank…………………………………………………………………...…………71

Figure 4.12 Average HPC concentrations in aerators under different water pressure and water tank……………………………………………………………………………72

Figure 4.13 Differences in HPC between aerators and control point………………...73

Figure 4.14 pH records over the cycles in the water tank and the faucets……..…….75

Figure 4.15 Water flow rate from different type of aerators and control point under 2 bar water pressure…………………………………………………….…………………76

Figure 4.16 Percentage of the water flow rate from faucet aerators relative to control point under 2 bar water pressure……………………………...…………………77

Figure 4.17 Water flow rate from different type of aerators and control point under 2.5 bar water pressure……………………………………………………………………..79

Figure 4.18 Percentage of water flow rate from faucet aerators relative to control point under 2.5 water bar…………………………………………………………………80

Figure 4.19 Water flow rate from different type of aerators and control point under 1.5 bar water pressure…………………………………………………………….………….81

Figure 4.20 The percentage of water flow rate from faucet aerators relative to control point all under 1.5 water bar…………………………………………..……………82

Figure A.1 Water Supply Material ………………………………………………106

Figure A.2 Water supply plumbing material in DIAC ……………………………..106

Figure A.3 Washroom in DIAC …………………………………………………107

Figure A.4 Sediment accumulation on the faucet aerator …………………………..107

Nomenclature:

At	Air Temperature
CFU	Colony Forming Units
C°	Celsius
C	Control point
CIA	Central Intelligent Agency
DEWA	Dubai Electricity and Water Authority
DIAC	Dubai International Academic City
DM	Dubai Municipality
EPA	Environment Protection Agency
ICU	Intensive care units
HPC	Heterotrophic Plate Count
K	Aerator type K
Lpcd	Liter per capita per day
L/ min.	Liter per minute
LEED	Leadership in Energy and Environment Design
MF	Membrane Filter
NFGNB	Non-fermenting gram-negative bacteria
N	Aerator Type N
P	Aerator Type P
PP	Pour Plate Method

PVC	Polyvinyl chloride
R	Aerator Type R
SP	Spread Plate method
U.A.E	United Arab Emirates
UPS	Urban planning council
U.S.G.B.C	United States Green Building Council
U.S.A	United States of America
Wt	Water temperature
W.H.O	World Health Organization
Δ	Difference in HPC concentrations

Chapter 1- Introduction

1.1 Worldwide water scarcity and climate change

Fresh water is one of the most valuable renewable resources on the planet, since it compromises 2.5% of the worldwide water, and only 0.77% of it is accessible (Write and Boorse 2011). Moreover in 2000 the World Health Organization (WHO) anticipated that one billion people lacked access to drinking water. Although the population is increasing worldwide, this number decreased to 884 Million in 2010 (UNESCO 2010).

Scarcity of the water is predicted to increase rapidly in near future due to population increase and climate change. As population increase, urbanization also increase, which means more water demand will be needed for industrial, agriculture and domestic use. According to the United Nation (U.N) population division 2008, the current number of the population in the world is six billion and this figure is expected to rise to about eight billion in 2025 (Wright and Boorse 2011). The Millennium Ecosystem Assessment stated that "A changing climate can modify all elements of the water cycle, including precipitation, evapotranspiration, soil moisture, groundwater recharge, and runoff. It can also change both the timing and intensity of precipitation, snowmelt, and runoff " (Wright and Broose 2011, P254). Table 1.1 presents possible effects of climate change on water resources.

Table 1.1 Possible effect of climate change on water resources, (Mihelcic and Zimmerman 2010).

Occurrence and direction of the tendency	Possibility of future tendency based on prediction for 21st century	Major Impacts
Reduction of land area and warmer and fewer cold days and nights	Almost certain	Effects on water resources and effect on some water supplies
Heat waves frequently increasing over most land areas	Very likely	Increased water demand and water quality.
Heavy precipitation events lead to storms which may mix the water supply with sewage systems	Very likely	Adverse effects on quality of surface water and ground water
Increase in areas affected by drought	Expected	More prevalent water stress
Increase in intense tropical cyclone activity	Expected	Power outage and disruption of public water supply
Increased occurrence of intense a high sea levels (excludes tsunamis)	Expected	Reduced fresh water availability because of saltwater intrusion

The U.S senator Paul Simon has anticipated that the next world war will be over water rather than oil (cited in Thompson and Sorvig, 2008). This prediction grows since countries upstream build dams to block the water and reduce the flow to downstream countries. Recently Nile river conflict appeared since ten countries are sharing the basin of the river. In addition to extracting water from coastal areas which may lead to an increase in salinity of the groundwater. This could results in country can be engaged with other country to catch water resources.

The limiting of water resources in addition the increase in demand for water due to population increase and urbanization, lead to water scarcity which occurs when water supply is less than $1000m^3$ per person per year. According to World Watch 1999, in 1995 the world population was 5.7 Billion and the water sufficiency was 92%, while the prediction for 2050 shows the population will be 9.4 Billion and scarcity might increase to 18% (Stein et al. 2006).

Gulf countries are one of the most areas where the gap between supply and demand is dramatically increasing. Thus these countries are trying to bridge the gap by depending on water desalination which has many consequences will be explained in the following section. Elnashar reported that up to 2003, more than 65% of the desalination sector in the world is operating in the gulf countries (Cited in Dawoud 2005).

1.2 Domestic water quantity and health

Providing domestic water is a basic need for human life. The quantity of water for domestic purpose is a very important feature in domestic water supplies since, it may affect public health. There is no available data to international standards specifying the minimum domestic water required for hygiene and public health, for instance, a declaration of Millennium goals which mentioned that: By year 2015 the people who have a lack of access to clean water should be reduced by fifty percent. However the quantity of water was not mentioned in the goal (WHO 2003).

Adequate water supplies may prevent the human life and protect them from many diseases. There is also a key relation between poor water supplying and hygiene. According to WHO 2002, about 1.73 million children die every year due to poor water supply (WHO 2003).

Gleick (1999) advised that 50 liters per capita per day is acceptable as basic water need for domestic distributed as following: 5 lpcd for drinking, 20 lpcd for sanitation services, 15 lpcd for bathing and 10 lpcd for food preparation. Although the figure of 50 lpcd seems small, it was projected that" by year 2000, 2175 million people will live in 62 countries that report average domestic water use below 50 lpcd " (Gleick 1999, p. 496).

1.3 The Development of Water Resources in Dubai

There are many factors that can increase the water consumption rate such as the climate, population, urbanization development and the higher income rate. The dominant climate in Dubai is arid where the average temperature in summer is 42 C°. The second factor is the population, as the population in Dubai (including expatriate) has increased dramatically from 862,387 in 2002 to 1,770,978 in 2009 which means higher demand for water (Dubai Statistics 2009). The third factor is urbanization development in recent decades due to the real estate boom. Last, but not least is the income rate, in 2009 the GDP for U.A.E was 38,900$ per capita which is one of the highest income in the world according to Central Intelligent Agency World Factbook (CIA 2010). In light of the aforementioned factors the water consumption rate in U.A.E was 550 L/C/Day in 2008 (Absel 2010). This is one of the highest rates in the world compared with the water consumption in the U.S.A which is 575

L/C/Day, and 493 L/C/Day, 374 L/C/Day, and 193 L/C/day in Australia Japan and Germany respectively (Anderson et al 2002).

The main source of water in Dubai is desalinated seawater via Arabian Gulf which contributes to 89.9 % of the total water supply. In addition to underground water which contributed 9.1 % of the supply in 2009. The supply is distributed in many sector as illustrated in the Fig 1.1 below, in 2009 the residential sector consumed 60.61 % of the total consumption followed by commercial sector with 24.9 % then industrial sector which consumed 3.7 % and others with 3.7 % (DEWA 2009). The irrigation sector which mainly uses treated wastewater is not included in the above data.

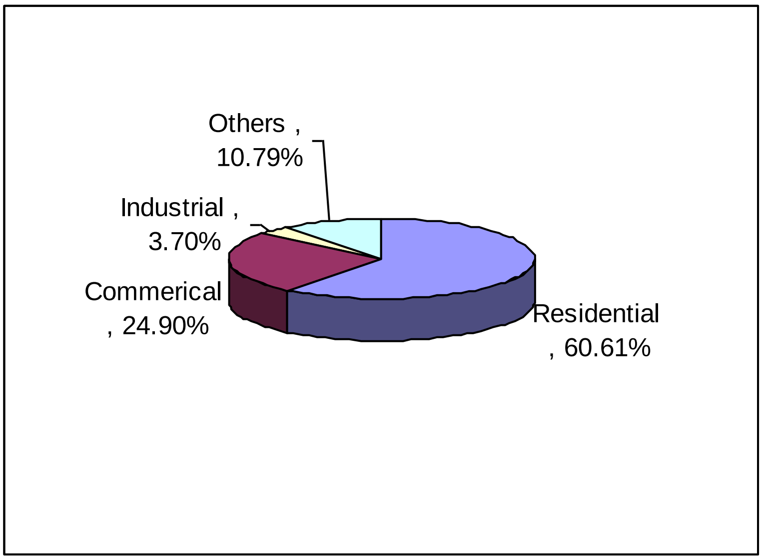

Figure 1.1: Water consumption in different sectors in Dubai, (DUBAI Electricity and Water Authority (DEWA) 2009)

Al-Mazroui and Al-Mansouri (2010, p.5) provided the following information:

> The amount of evap./ transpiration is more than 75% of the total annual rainfall, and that about 15% runs off to the sea leaving only 10% to recharge the aquifers. Abstraction of ground water is more than a thousand cubic meters a year, 79% of it being non-renewable, resulting in drying or salination of aquifers.

Worldwide, 26% of seawater desalination capacity is located in U.A.E (Lattemann & Hopner 2008). According to Dr. Mariam Alshenasi, a spokesperson for U.A.E ministry of water and environment: " the costs of production of desalinated water in U.A.E are estimated at 11.8 billion Dirham annually, an average 7.16 Dh per cubic meter " (H2O 2010, p.6). In addition to the high cost of desalinated water production, there is a negative impact on the marine environment via the discharge of the concentrate and chemicals to the water and air pollution resulting form energy consumed in the process.

In recent years, the reliability of desalinated water resources might be compromised due to red tide which occurred in the gulf and affected the water quality and resulted in interrupted to water production from the plant. Reference to (Kakande 2008) in November 2008 the Ras Al Khaimah desalination plant was closed for one week due to red tide consequently desalinated water supply was stopped to the resident.

1.4 Water consumption in the buildings

The Unites States Green Building Council (USGBC) and world watch institute mentioned that, the building sectors consume 16% of global freshwater (cited in Foster et al 2007). Using a large quantity of water increases the operation and maintenance cost of the buildings thus, application of an efficient and complete water management plan could reduce the utility bills. Another point is that, considering water efficient fixtures and appliances in the design stage could reduce the size of the pipe lines, storage size and the pump capacity, all of which have cost implications (LEED 2009).

DEWA does not provide data about domestic water usage in buildings. According to the Environment Agency in the U.K, typical water use in England and Wales from 1997-1998 was as illustrated in table 1.2. The table illustrates that, bath shower and wash basin consumed 33% of the total domestic water consumption. In reality the weather in the U.A.E is very hot compare with the U.K weather consequently, the below figures are expected to be more in the U.A.E.

Table 1.2 Typical water uses in the U.K, (Sustainable building Design Manual 2004)

Water use	Percentage of the total consumption
Bath/Showers/hand basin	33%
WC flush	25%
Clothes washing	14%
Dish washing	8%
Garden use and car wash	7%
Others	3%

Many regulations emerged in different parts of the world in order to regulate and enhance the sustainability. These regulations focus mainly on buildings since buildings are responsible for 30% to 40% of greenhouse emissions in the U.S.A (Jones 2008), which are the main reason for global warming and climate change. One of the green building features is water conservation. As a result many standards such as LEED and BREEAM specify the water flow rate and provide points according to their ranking system for the buildings to achieved water saving, so the buildings can be certified as green.

One of the water main conservation tools for domestic water supply is the use of water saving plumbing fixtures such as faucet aerators, which are mounted at the end of the spout and defined as "the air mixed with the water and despite a reduced water flow" (Bokalders and Black 2010, p. 322). Faucet aerators have been invented in 1950's and hence then, many alterations have been implemented in order to improve its general appearance and reduce its cost. In the last two decades, changes were applied to make these aerators comply with green building guides, so that the maximum water flow rate is now 6 Liters/Minute which contributes to water saving.

1.5 Sustainability in U.A.E

The United Arab Emirates is located at the south of the Arabian Gulf. It is located between longitudes 22° and 26.5° North and latitude 51° and 56.5° East. The total area of U.A.E is 83,600 km. It has a tropical desert climate with averaging 65 mm of annual rain. In summer (June to September) the daily average temperature exceeds 45C°.

According to the World Commission on Environment and Development 1987, sustainable development is defined as "development that meets the need of the present generation without compromising the ability of the future generation to meet their needs " (Moughtin & Sh. 2005). If the current practices of water consumption remains without improvement and without implementing sustainable usage then, future generation will struggle to put it simply, worldwide freshwater has become precious resources. According to World Health Organization more than one billion people lacked access to safe water supply sources within one kilometer of their houses. (W.H.O 2003)

Based on global footprint network 2010, U.A.E has the highest ecological footprint thus, needing action to curb the overconsumption. Scarcity of the water resources in U.A.E led the country to meeting its water demand mainly from seawater desalination as main sources and brackish water desalination as a second source (DEWA 2009). The water desalination process requires a lot of energy which means more CO_2 emission which, in turn is the main cause of greenhouse gas that is the main cause of global warming.

Al-Mazroui and Al-Mansouri (2010, p.7) provided the following information:

> The harsh arid climate of the U.A.E with low rainfall presents several difficulties for the sustainable supply of water. The U.A.E has one of the lowest national renewable water resources capacities, which on a per capita basis equates to 64 m3 per year, only of the order of 1% of the world average.

The emergence of green building legislation aims to enhance sustainability. One of the green building features is water saving via plumbing fixtures since it has the potential to save water as well as energy. However, a substantial study should be conducted in order to avoid any negative side effects from using such fixtures.

Recently in the U.A.E many campaigns were conducted to encourage people to use water devices such as faucets aerator. Mr. Rachid from DEWA stated that: A team from DEWA performed many school visits in order to enhance the water saving behavior and improve the awareness of the water scarcity and benefits of water conservation. To do this, they built a model of two taps, one with water saving aerator and the with conventional tap aerator, then they allowed water to fill two bottles at the same time. Two stop watches were used to record the time required to fill the bottles. The results showed that, the bottled filled by faucet with aerator consumed more time than the bottle filled by the normal faucet which meant, the water flow from faucet with aerator is slower than the normal faucet. This demonstration was used to convince the students of the importance of the aerators. In addition The Environment Agency-Abu Dhabi has distributed faucet aerators free of charges to the public to encourage them to reduce water consumption and they recently announced that 76,494 water saving aerators have been fitted in 4,563 different buildings in Abu Dhabi.(Environment Agency 2010).

Furthermore Abu Dhabi urban planning council (UPC) Lunched Pearl rating system for the buildings via Estidama Program, in order to achieve sustainability in buildings. They claimed that, this system is suitable for arid weather area such U.A.E (Abu Dhabi Urban Planning Council 2010).

1.6 Side effects of using aerators:

In the middle of the last century Elie P. Aghnides, a Greek inventor noted that, the water felled from mountains stream is more effectively than the water flowed from normal water pipe due to aeration of the water during falling thus, breaking it in to bubbles foam, as a result he provided a set of metal screens in water pipe and he found the water outflow from the water pipe is bubbly, clean and soft. (Juror 1946)

Since 50's until 80's of the last century many changes had been integrated to original aerators in order to decrease the cost, improve the appearance of the aerator and to protect the aerator from becoming damaged therefore in 1981 the aerator became concealed in the faucet (Elie 1983)

By 1992 many modifications had been adapted to the aerator to comply with U.S Environmental protection Agency (EPA) and other standards requirement to achieve the maximum water flow quantity. This is positive in one way however, it may has unexpected side effect.

According to Heroes of the U.A.E (2011) “When a Water-saver is fitted it acts as a regulator on the tap, ensuring that the water always flows at a constant rate. This means that whether the pressure is high or low, you still enjoy the same flow rate. It also means that an incredible amount of water and energy – which are both precious and finite resources - are saved in the process”.

New inventions or innovations may be associated with negative side effects however; consideration of comprehensive criteria reduces negative impact of using innovation. In 1940th pesticides were invented in the U.S.A, and they eliminated the insects dramatically, however irresponsible use of them led to contamination via the food chain. In 1962, Rachel Carson, one of sustainability's pioneers published her book, Silent Spring which resulted in the international ban on the use of DDT (Wright & Broose 2010). The lesson learned from this event was that, immediate benefits may have unforeseen negative effect in the long-term if all sustainable features are not respected.

Although advantage may achieved via using the water faucet aerators, many epidemiological studies have been done by Nguyen et al. (2008), Orenstein et al (2006), Kappstein et al. (2000), Weber at al. (1999) and Wang et al. (2009) which correlated outbreaks bacterial infections in health care centers to faucet aerators, and they concluded that the aerators might work as reservoirs for bacterial growth, thus increasing bacterial concentration in faucet aerators may lead to water contamination.

1.7 Test for water quality evaluation

Heterotrophic Plate Count (HPC) test in water supply system is very useful tool in assessing the water quality and the potential of bacteria to re-growth in the system as well as to evaluate the "microbial growth on material used in water distribution system"(Carter et al. 2000).

1.8 Rational for the research:

Application of water saving campaign may be associated with negative impact on human health thus need integrated study to avoid such impact so, this research attempted to answer the following questions. Would faucet aerators affect bacterial growth, which may be affect the water quality? What is the optimum length of time between maintenance of the aerator to avoid its deterioration?.

1.9 Structure of Dissertation

In the following chapters, a comprehensive review of previous studies related to faucet aerators and factors enhance bacterial growth in the water system are discussed. In chapter three the method and procedure used in this research are explained, then in chapter four and five the results and the outcome are presented and discussed comprehensively. Finally in chapter six the conclusion and recommendations will be presented.

Chapter 2- Literature Review

2.1 Needs for water conservation

Water is one of the most remarkable resources in the world. Even though it covers almost 70% of the earth surface; more than 97.5% of this water is salt and is not suitable to be used as potable water. The remaining 2.5% is fresh water of which 68.9% is kept in glaciers and 0.9% is in permafrost. Therefore, the remaining 29.9% is fresh groundwater and 0.3% constitutes freshwater lakes and rivers which are regarded as renewable (Benggeli 2010).

Water plays vital role in our life. Worldwide, 70% of water is used in irrigation, 20% for commercial-industrial activities and 10% for residential uses. Moreover, water is essential for building construction since the production of one ton of bricks needs 2200 Liters of water. One ton of steel requires 1.32 million Liters. Furthermore, huge quantities of water are needed for electricity production in power plants (Stein et al 2006).

There is a significant link between domestic water consumption (which is used for personal hygiene in addition to washing clothes and dishes) and energy demand. In winter, water needs to be heated to a certain temperature before being used for different purposes. Another point is that, cold water requires energy in order to get pumped from the underground or desalination plants via pipe lines to reach reservoirs or end user points. Furthermore, energy is required for the transportation of waste water to designated treatment plants in order to get treated. Table 2.1 shows indicative values of energy used in different process to deliver water in California.

Table 2.1: Energy consumed for water production, (Harvey 2006)

Process	Maximum energy used kWh/M^3
pumping Groundwater	0.6
Desalination of seawater	3.89
Desalination of brackish groundwater	1.38
Water treatment	0.06

2.2 Techniques of Indoor Water Saving

Water is considered to be one of the most valuable resources on land and the trend of demand is increasing rapidly mainly due to population increase. Thus looking for new alternatives is a very important step toward sustainability. In 1992, legislation for conserving water was approved by Energy policy conservation acts in U.S which mandated that all new faucet, showerheads and toilets should have the water conservation features (Foster et al. 2007).

In April 2010, Dubai Electricity and Water Authority issued green building regulations which include rules that aim to save water. The law is mandatory for all new buildings. It states that “water conserving fixtures must be installed meeting the criteria in below table " (DEWA, P11, 2010). It is noted that the regulation does not recommend specific type of the fixtures.

Table 2.2 Water Flow Rate for Different Fixtures according to DEWA, (DEWA 2010)

Fixture type	Flow Rate
Showerhead	8 Liters per minutes
Hand washing basin	6 Liters per minutes
Kitchens sinks	7 Liters per minutes
Dual Flush toilets	6 Liters per Full Flush,3Liters per part Flush
Urinal	1 liter per Flush or water less .

There are several devices in the market to enhance water consumption conservation such as:

2.2.1 Alarming Visual Display monitors:

It is a new technology which enhances water and energy savings by measuring water flow and temperature of the water and giving an alarm when a certain volume of water is consumed. Fig 2-1 shows the shower monitor.

Fig 2.1 shower Monitor. (waiTEK 2009)

Willis et al. (2010) conducted a study by installing alarming visual display monitors to evaluate the effects of the device on shower end users water and energy saving. The shower device has ability to lock water consumption at 40 Liters. In addition to display the reading of the water flow rate, duration and temperature, this enables households to shower more efficiently. Also at the end of prearranged shower duration it maintains for one minute time to alarm that, it is the time to quit the shower. At the end of the study, there was an average of 27% reduction of water consumption for shower which resulted in additional saving in energy.

2.2.2 Low Flow Fixtures:

There are various types of low flow fixtures. Several types are listed below:

A-High efficiency toilets

Which have been defined by EPA in U.S and the pluming industry; as a toilet that flushes with an average of 20% less water per flush than the conventional toilet. One of those toilets is dual flush toilets which are designed for slight and excessive flush with maximum flush volume 1.28 Gallons per flush (NAHB 2001).

The second type is water saving cisterns which complies with the regulation 6 L per Flush. The third type is delayed flush cisterns which stops the cistern from becoming full of water before the flush is completed (Ideal standard 2005).

B-Shower Head

The ordinary shower head supplies up to 25 Liters per minute. Thus installing a water restrictor between the water valve and the shower hand can reduce the flow up to 9 Liters per minute (Ideal standard 2005).

Fig 2.2 showerhead (EPA 2010)

A study conducted in U.S.A showed that the use of lower flow showerheads can save up to 27 liters each day per person. It also saves an equivalent of 444 kWh of energy used for water heating per person (Roaf 2007).

C- Dry Urinals:

Although dry urinals have been known since many years in Europe, they were recently effectively used due to rising cost of water and waste water bills. There are two types of dry urinal. The first type is the Traps with floating sealing liquid system (see Fig 2.3) where it traps urinal with higher viscosity floating sealing liquid, and do not mix it with water so, the urine flows below it which prevents unpleasant odors from spread out. Thus using such sanitary ware reduced water consumption. The second type is the Mechanical working traps (see Fig 2-4). It has a sensor which detects the users and allow for the urine to overflow into the trap (Demirize 2006).

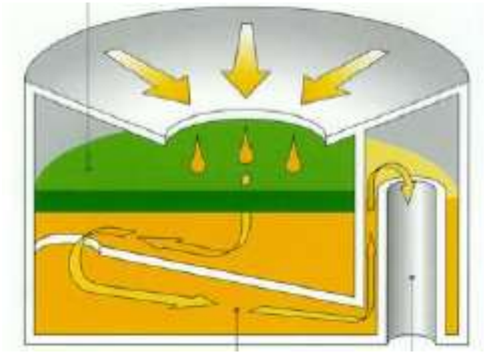

Fig 2.3: Trap with floating sealing liquid (Demirize 2006).

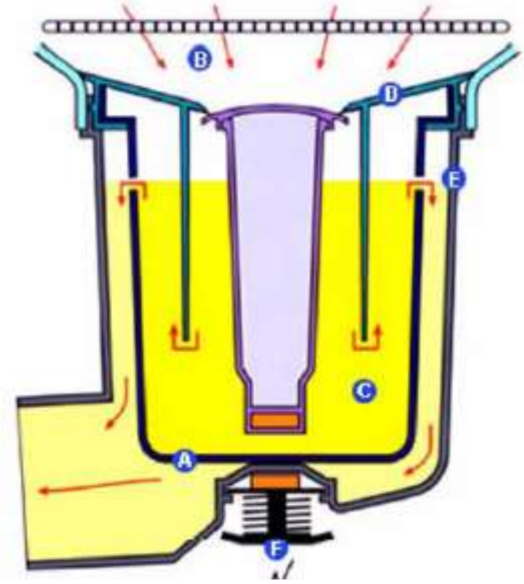

Fig 2.4 Mechanical Working Traps. (Demirize 2006).

D-Faucets

There are different technologies to achieve water saving these include but are not limited to the following:

1-Self closing taps

In this type of taps, water flows for a period of time from 10 to 15 seconds before closing by itself (Ideal Standard 2005). This type requires regular inspection and maintenance to avoid it's fail in open position (Garrett 2000). Figure 2.5 shows image of the tap.

Fig.2.5 Self closing taps (Prestomat2000 2011).

2-Sensorflow taps

The working concept of this technology is based on user hand detection, where the flow shuts after three seconds from hand removing moment and the valve remains open for maximum of 30 seconds in case the hand is not removed (NAHB Research Center 2000). Furthermore, in other brands the water flow continues as long as the hand is under the tap and closes immediately once it away (Plumber surplus 2010).

3-Water saving Faucets Aerators

The function of the aerator is that it can mix air with the water thus reducing the water consumption (Neoperl 2010). (See Fig 2.6).

Fig. 2.6 Faucet Aerator (Environment Agency Abu-Dhabi 2011)

2.2.3 On site gray water recycling

The water used for washing machines, kitchen sinks, dishwasher and bathing contribute to up to 60-70% of domestic water uses which result in gray water. The treatment includes a serious of steps; fine screen, equalization basin, rotating biological contactor, pre filtration storage tanks, sand filtration and disinfection. The reuse of this water reduces water consumption from main sources (Friede et al 2005).

2.3 Principal function of the low faucet aerators:

The main function of the aerator is to drive air in to the flow of the water and thus produce considerable and whiter stream (Neoperl 2010.). It consists of perimeter metal frame (housing) insert which may be P.V.C or wire mesh and a washer (see Fig 2.7)

Figure 2.7 Aerator parts (Neoperl 2010)

According to Neoperl, a study has been conducted to evaluate the performance of the aerator with wire mesh verses the aerator with p.v.c mesh for duration of five years under the following conditions: water temperature at 20 C°, room temperature at 20 C°, the study concluded that the aerator with p.v.c mesh is more efficient than the one with wire mesh as a result of the accumulation of lime on the middle of the wire mesh (Neoperl 2010).

2.4 The health issue related to potable water:

World wide access to safe potable water is one of the basic human rights however, no clear definition of microbiologically accessed since what may be accepted to the people in good health condition it may be deadly to immune compromised and geriatric inhabitants (Ford, 1999).
In general the health problems that occur due to drinking polluted water can be classified to infection diseases, cancer, endocrine and fertility illnesses. In addition, it has impacts on the taste and odor of the water thus affecting its quality.

Orenstein et al. (2006) investigated the presence of Pseudomonas and Stenotrophomonas in an intensive care unit (ICU), the main reason for the investigation was the dramatic increase in colonized and infected babies in the ICU, so the investigation included surveillance of the way of the baby’s life, sampling of the environment of ICU, examination of disinfection steps of all equipment and assessment of hand cleaning way. The pathogens were not discovered except from the water aerators where the revision of the maintenance procedures of the plumbing system proved periodical cleaning of the aerators. Although the aerators had been installed since 1992, they have never been replaced thus caked minerals was accumulated on them. The aerators were changed and the number of infected babies has dramatically decreased. The researchers concluded that water aerators contamination plays a crucial role in ICU outbreak with gram-negative organisms.

Kappstein et al. (2000) investigated outbreak of bacterial in pediatric patients which resulted from Acientobacter Junii, the investigation included many environment of water and air cultures from the rooms in the affected area. All samples were negative except one from faucets aerators in staff rooms, the aerators were made from wire mesh which allows the sediments from the water pipe to accumulate and enhance the growth of bacteria.

Weber et al. (1999) pointed out a trace of an outbreak disease with Stenotrophomonas maltophilia by the contamination of faucets aerators in hospital, the aerators were made from stainless steel wire mesh.
They concluded that low contamination of potable water in the hospital led to bacterial magnification on the aerators thus the pollution of the faucets aerators may act for nosocomial hazard in hospitals.

Wang et al. (2009) conducted a study to evaluate the relationship between the outbreak of infection caused by non-fermenting gram-negative bacteria (NFGNB) and the contamination of faucets in intensive care units in Taiwan. They remarked that 30% of the checked faucet aerators were contaminated with some species of NFGNB while other species of NFGNB cultured from the patients could not be traced to faucet aerators.

On the other hand Huang and Lin (2007) conducted a study for 27 weeks to evaluate the effect of faucets aerators and laminar devices in promoting the growth of Legionella species in a hospital in Taiwan. Even though the water system in the hospital was contaminated with Legionella, they could not find significant difference in the concentration of Legionella in the faucets with or without aerators. At the end of their study they were not able to confirm the previous studies which showed that the aerators installation may promote the Legionella growth in it.

2.5 Heterotrophic bacteria

Heterotrophic Bacteria Counts (HPCs) which are also known as standard plate count or total bacterial compromise aerobic and anaerobic bacteria that extract their carbon and energy from organic nutrients for their growth. They can be found in air, soil, food and water (Allen, M. 2004). Table 2.3 illustrates HPC bacteria represent in drinking water.

Table 2.3 HPC bacterial in Potable Water, (Mrlechavallier et al. 1980, Herson and Victoreen 1980, and Wacker 1995 cited in Allen 2004)

HPC “genera “ survive in potable water	
Acinetobacter	Klebsiella pneumonia
Acinomycetes	Methylomonas
Alcaligenes	Micrococcus
Aeromonas	Mycobacterium

Aeromonas hydrophila	Morexella
Arthrobacter	Nitrobacter
Bacillus	Nitrosomonas
Beggiatoa	Nocardia
Citrobacter freundi	Proteus
Corynebacterium	Pseudomonas
Crenothrix	P. cepacia
Desulfovibrio	P. fluorescens
Enterobacter ogglomerans	P. maltophilia
Enterobacter Agglomerans	Serratia Liquefaciens
Enterobacter cloacae	Sphaerotilus
Escherichia coli	Sphingomonas
Flavobacterium	Staphylococcus
Flavobacterium meningosepticum	Streptococcus
Gallionella	Streptomyces
Hafnia alvei	Yersinia enterocolitica

According to the American Public Health Association, American water works Association and The Water environment federation (1999), there are three distinct approaches for HPC, Pour plate (PP) method, Spread Plate (SP) Method and, Membrane Filter (MF) Method. Many studies proved that HPC outcomes are varied and that depends on "growth medium, incubation time and incubation temperature" (Reasoner 2004). The SP method normally produces more count than PP method.

Despite the fact that HPCs includes all bacteria depending on organic nutrients for their survival, "all HPC methods enumerate only a fraction or subpopulation of heterotrophic bacteria". Also it is impractical to specify the ratio of each subpopulation (Allen 2004). Moreover, some bacteria such as Legionella and Myco-bacterium avian complex use organic nutrients for their survival however, they are not growing on HPC media accordingly, in order to investigate the presence of Legionella in potable water, other standard methods should be followed (Allen 2004).

The HPC Methods are useful in supervising the microbiological water quality in distribution system (Grabow 1996, Edberg, Allen 2004 and Pavlov et al 2004 cited in Francisque at al 2009). Furthermore, according to Reasoner (1990), HPCs methods are very important in the evaluation of bacterial growth on elements utilized in the distribution system, and bacterial re-growth in treated potable water (cited in Allen et al. 2004).

Many studies concluded that there is no relationship between medical problem and high concentration of HPC genera in drinking water and, there is insufficient clinical evidence to substantiate specification of maximum level of HPC concentration in potable water. According to Pavlov et al 2004, in Japan and Germany the maximum level of HPC bacteria is 100 cfu/ml. Furthermore, in North America the upper limit is 500 cfu/ml (cited in Francisque et al. 2009). In Dubai, a threshold of 500 cfu/ml is set as a standard for surveillance of the drinking water quality.

According to the U.S Safe Drinking Water Act, the national primary drinking water regulation, the maximum level of HPC is 500 cfu/ml. "There is no consistent correlation between results from PP method and any other approved HPC method; therefore another HPC method cannot be substituted for the purpose of the U.S drinking water regulations"(

Reasoner 2004, p.313). In this study HPC test will be used as tool to evaluate the bacterial growth and re-growth in the faucet aerators.

2.6 Pathogens in drinking water:

There are many types of bacteria but; it is only the pathogens that might harm the human health. Pathogens that may produces disease through potable water can be classified based on their size in to Helminths (>100µ), protozoa (5-100µm), Bacteria (0.5-1µm) and viruses (0.01-0.1µm). Therefore it is essential to treat the water prior it reaches to consumers; however there are many source of contamination during the stages of the water supply cycle illustrated in the following table.

Table 2.4 Sources of water contamination, (Gray 2008)

Major sources of Potable water Contamination	
Resource	Natural , land use , pollution
Treatment	Unit process effectiveness , chemicals add to purify the water
Distribution	Plumbing and fixtures material, organism, pollution
Home plumbing	Pluming and fixtures material, pollution deficient fittings

2.7 Factors enhancing the growth of microbiological organism in the water distribution system:

Many studies pointed out that bacteria have a potential for re-growth in the distribution system. This growth is influenced by many factors which create an ideal environment for bacterial growth. These factors are presented below:

2.7.1 Temperature of the water

Temperature plays a central role in bacterial growth since the main structure of the bacteria is the three-dimensional protein which acts as membrane transport mechanism and as an enzyme in addition to acting as a structural component. The three dimensional proteins of the bacteria is due to its hydrogen bonds which are weak. Thus increasing the temperature may result in breaking the bonds consequently affecting the bacterial function (Strelkauskas, J. et al. 2010).

Bacteria may be classified based on the temperature of the media where it can survive in. Some kinds of bacteria can live between 0 C° to 15 C° which are called Psychrophiles bacterial, while Psychrotrophs can survive in Temperature from 20 C° to 30 C°. Mesophiles can exist in temperatures between 25 C° to 40 C° which is moderate degrees and include pathogen bacterial to the human. Finally Thermophiles bacterial can grow at Temperature above 45 C° (Strelkauskas, J. et al. 2010)

In general, the presence of coliform has been noted when the water tap temperature was more than 15 C° (Bartram et al 2003). Beside that many studies showed that the hot water system plays a key role in promoting the existence of Legionella which normally develop in temperatures between 20 C° and 45 C°. Moreover, it can survive in higher temperature up to 60 C°.

Furthermore, the United Kingdom Department of health and social security code of practice prefers the storage of cold water below 20 C° and the hot water should be stored at 60 C° to 65 C° (Bartram et al. 2003).

Francisque et al. (2009) noticed that HPC bacterial level was not discovered in 75% of water samples collected from water distribution system when water temperature was less than 4 C°. When water temperature raised to more than 18 C° a significant increase in HPC level was identified.

2.7.2 Plumbing Materials

Rogers et al. (1994) conducted a study to investigate the effects of the plumbing materials on the biofilm formation and Legionella Pnumopila. They concluded that plastic pipes enhance the concentration of the biofilm in contrast to the copper pipes which limit the colonization of the water system by Legionella. Moritz et al. (2010) noted in their experiment that biofilms presence in copper materials were less in comparison with plastic and elastomeric materials.

On the other hand Camper (2003) concluded that iron pipes have more potential of enhancing bacterial growth than P.V.C pipes (Shane 2008). Corrosion also influences the roughness of the pipe and accordingly, promotes the bacterial re-growth in the distribution system (Niqutte 2000 in Shane 2008, p.32)

According to the manufacturer Neoperl (2010), closing water faucets in hospitals leads water drops to be trapped inside the aerator and in presence of warm temperature thus evaporate the water and leave sediments as source of food for biofilm. Also, as previously mentioned, the function of the aerator is to mix air with water to produce an aerated stream of water. In the case of health care buildings, the air around the faucets mostly contains bacteria, thus mixing the water with this polluted air can lead to its contamination (Neoperl 2010).

Hargreaves et al. (2001) investigated the water contamination in a hospital following a flood in Grand Forks. The water samples entering the hospital from the water supply system comply with water quality standard however, the water from faucets was contaminated. Water samples were collected randomly and HPC test was performed. Statistical data was analyzed via Epi Info. Version 6. A comparison was performed between the HPC results from 110 manual faucets verses two brands of electronic faucets, 34 number of brand A faucets and 25 number of brand B faucets. The results showed that HPC exceeded the limit in 22% of the electronic faucets where as 11% of the manual faucets exceeded the limit. Furthermore, there was a significant different in HPC levels from electronic faucet type A and B.

A hyper chlorination treatment for the water supply was performed then after 2 months, similar tests were conducted. The results revealed that brand A faucets promoted the HPC growth. Also samples from spigot (plumbing fixtures) which were recently fixed in the water pipe were tested and the results showed that HPC level is below the threshold level.

All brands A electronic Faucets were replaced with manual faucets. Water samples from those faucets were tested and the results revealed that the HPC level is below the threshold level and matches the level from other faucets. The researchers concluded that a certain brand of electronic faucets can support microbial re-growth in water.

2.7.3 Water flow velocity

Ollas et al. (2003) in Lehtola et al. (2006) concluded that, increasing the water flow velocity could prompt the production of bacterial number in biofilm. Furthermore, Cloete et al. (2003) in Lehotal et al (2006) noted that the biofilm was separated when the flow velocity was 3m/sec.

Ciesilski et al. (1984) conducted a study to investigate the role of stagnation and obstruction of water flow in the isolation of Legionella pneumophila from hospital plumbing. They suggested that the elimination of stagnation in hot water tanks may reduce the L pneumophila concentration.

2.7.4 Biodegradable Organic matter

Momba (2000) found that biodegradable organic matter in treated water or from material in contact with drinking water provides the foundation for biofilm re-growth (Shane 2008). Additionally, Francisque et al. (2009) observed that HBC level was very high in potable water samples because of biodegradable organic matter in the water.

2.7.5 pH

pH is a value that represents an indication of the alkalinity or acidity of the water. The pH meter contains values ranging from 1 to 14, where a value of 1 illustrates the highest level of acidity and value of 14 illustrates the highest level of alkalinity. Most of bacteria favor the neutral of pH 7 for its growth, while some of them have the ability to grow in acidic environment such as acidophilus.

Carter et al. (2000) found a correlation between pH and HPC bacterial. Francisque et al. (2009) tested many water samples for a period of three years and, found that higher pH level in water increases HPC concentration, also they observed that HPC level exceeds 100cfu/ml when pH of the water is beyond 8.5.

2.7.6 Existence of disinfectant residual

Mombo (2000) noted that, providing chlorination reduced bacterial number in water. Furthermore, re-growth of bacteria occurred after the chlorination residual was decreased (Shane 2008).

Nguyen et al. (2008) conducted an investigation for the reason of water taste and odor complaints by residents of two new buildings which were occupied immediately after completion. The Buildings have water saving aspects. The water distribution system was evaluated by using heterotrophic plate count (HPC), Aeriginosa and Legionella tests. The results showed that, water taste and odor was caused due to decay of chlorination residual in the water distribution system. The Researchers suggested that minimizing water residence time in the tanks in addition to limiting nutrient at the water treatment plant might reduce microbial re-growth.

With reference to a study conducted by Francisque at al. (2009), it showed that the presence of free residual chlorine in water distribution system with concentration less than 0.3mg/l enhances the growth of HPC bacterial. Consequently, the researchers advised to keep free residual chlorine concentration higher than 0.3 mg/l in order to avoid high level of HPC bacterial.

2.8 Aims and Objectives of the study:

Currently the movement of sustainable design of the built environment is attempting to incorporate different solutions to preserve the earth's resources, mainly its energy and water resources. However, sometimes some unintentional fault occurs during the implementation of sustainable practice. For example, utilizing faucet aerators in water conservation may accomplished with negative impact on human health. So the question may rise; does this usage cover all aspects related to sustainability? Consequently the aims and objectives of the study will be mentioned below.

The aims of the study:

Indeed the research has main and minor aims. The main aim is to investigate the assumption which evokes that bacterial growth may be augmented by using faucets aerators. The secondary aim is to evaluate the current maintenance practice of the aerators, which is necessary to avoid any risk to the human health due to bacterial growth.

The objectives of the study:

There are many objectives to be achieved through this research as explained below:

In the beginning of the study, an interview with facility management of the building where the experiment is conducted, in order to know their current practice for the maintenance of the existing aerators, also to set different water pressure in different washrooms with 2.5, 2 and 1.5 water bar consequently it will affect the water flow.

Three different types of the aerators in addition to existing water spray type are under study and are being monitored is through control points (faucets without aerator). The study period will be for six months in 4-

weeks cycle from October to March, in which water samples from the faucets will be collected in each cycle.

A bacterial counting approach will be used HPC Pour plate method to test the water samples in order to monitor potable water quality changes after treatment. Other parameters which will be tested in each cycle include water temperature, inside air temperature, water flow rate and pH of the water. The independent variables will be time, water pressure and type of the faucets aerators , while the dependent variables will be the total bacterial count and water flow rate.

The concentration of the bacteria is compared to standard values, taking into consideration the time consumed by the bacteria to reach to critical levels. Based on the results recommendation for the best maintenance schedule will be proposed at the end of the study.

Chapter 3-Methodology

3.1 Previous Methods

As discussed in the previous chapter that bacterial re-growth in water distribution system is influenced by many factors. One of these factors is the plumbing fixtures such as faucet aerators. As the aerator hindering the water flow thus accumulates sediment on the internal side of the aerator which may lead to bacterial growth. In the following paragraphs presentations of many studies are listed to investigate factors may enhance different outbreaks in hospitals.

Kappsstein et al. (2000) carried out a study to investigate the source of Acintobacter Junii in a Pediatrics oncology hospital which caused an outbreak of bacteraemia consequently; the researchers reviewed the medical charts of the patients to assess factors and which source of the bacteria. Two types of samples were also taken from all faucets, the 1st type were cultured after dismantling the water aerators and immersed in sterile saline, and the 2nd sample which was (100Ml) of water from the faucets after removing the aerators and allowing the water to run for a few minutes.

It was noted that the aerators had wired mesh which accumulated sediments from the pipe. Furthermore, environmental sampling of surfaces and tools in different rooms in addition to air samples were taken from air-conditioning units from the medication rooms. Finally specimens were cultured from the hands of the staff working in infected departments in the hospital.

Investigation of Junii bacteria was carried out using automatic laser fluorescence analysis of randomly amplified polymorphic DNA. The results showed that the bacterial type found in the patient's bloods were identical to the one cultured from the staff room faucets aerators, while other cultured samples from the environment and the air were negative. The researchers concluded that the water supply system had become slightly contaminated and the concentration of the contamination was greater in the aerators. Finally a new type of aerator without the wire mesh was proposed and replaced the wire mesh aerator, water samples were taken and analyzed. The results showed no junii bacteria.

Wang et al. (2009) conducted a study to investigate the relationship between the colonization of nonfermentatative gram-negative bacilli (NFGNB) in faucets aerators and the infection of patients in intensive care units (ICUs). The study continue for four months, samples were taken from 162 faucet aerators in seven units.

The faucets were located near the patient's beds; however the water samples taken from the central water supply were negative. A cotton swab was applied to swab the internal surface of the aerators, then the swabs were inoculated onto sheep blood agar plates and incubated at 37 C° for 3 to 5 days, the samples of colonies were classified according to standard. The results showed that 33% of the cultured aerators were contaminated with NFGNB, which correlated to the infection of the patients in ICU. The investigators concluded that the results supported previous studies that contamination of the water from the faucets developed at the point of use in hospitals.

Orenstein et al. (2006) reviewed the number of patients infected by Pseudomonas in 2003, 2004 and 2005 in a neonatal ICU. They noted a dramatic increase in the total number of infected babies in 2005 during August and July. Consequently they conducted an investigation to find out the reason for the outbreak by monitoring the cultures of all the babies, took many samples of the ICU environment and reviewed the disinfection procedures of all equipment. The cultures indicated that there was no Pseudomonas in all samples except for the aerators.

In cooperation with the facility team in the hospital, a review of fitting and maintenance records for the plumbing fixtures was carried out which showed that: the faucet aerators had been fitted in 1992. And although weekly surface cleaning of the aerators had taken place, the aerators had never been changed since they had been fitted. The aerators were dismantled and changed then, samples were collected and tested. The results showed a reduction in infection in patients. They concluded that the contamination of water, faucets and fixtures played a key role in neonatal ICU outbreaks.

Ciesielski, et al. (1984) studied the cause of nosocomial Legionnaires Disease that had taken place in a medical center. Inspection and observation of the medical center water supply system demonstrated that Legionella Pneumophila was presented in the system, which included the tanks, showerheads, faucet without barriers of water flow, and faucets with "backflow preventers, vacuum breakers and aerators ". Evaluation of the water supply system showed that stagnation of the water in five tanks supplying hot water to the center led to re-growth of the bacteria. The study continued from late 1981 until April 1983.

On a monthly basis, 50 ml water samples were taken in sterile containers from drain valves in the bottom of each tank after flushing the water for 10 seconds. The temperature of the water was recorded immediately after the sampling. Showerheads were sampled monthly (using swab) from their inner surfaces. At the end of the study 72 faucets were sampled by swab and water samples. All samples were incubated onto ager plate at 35 C°.

The collected samples from the tanks during the initial 18 months were found to have L. pneumophila. Subsequently an action was taken to minimize the stagnation of the water in the tanks. After that further samples from the tanks were taken. The results showed that the bacteria concentrations were under the threshold level. Moreover 50% to 70% of the samples taken from showerhead were positive although there was low level of L. Pneumophila in the tanks. In addition three samples out of twelve taken from the faucets were found to be positive.

Further investigation showed that the 3 positive samples were located in laboratory area and those faucets have aerators. The aerators obstructing the water flow caused stagnation to the water and provided a medium, and surface for L. Pneumophila. The aerators were dismantled and kept in 70% alcohol for sterilization purposes then, further samples were taken. The results found that after one months of use, the samples were positive again.

Stojek et al. (2008) assessed the level of contamination of water supply systems in six hospitals in Poland. Sixty seven of water samples were collected from faucet with aerators and showerheads in the hospitals, 500 ml sterile bottles were used for sampling. A standard test was performed to identify the presence of Legionella and non fastidious gram-negative bacteria in the water. Agar plates were incubated for 24 hrs at 37 C$^{\circ}$ to detect the Legionella and non-fastidious Gram-negative respectively.

The data were analyzed using a piro-with-W-test for distribution and spearman's rank test for correlation coefficient with the use of STATISTICA for windows v.5.0 package. The researchers confirmed that the aerators or other attachment on faucets or showerheads enhance the growth of Legionella.

Weber et al. (1999) conducted a study at the University of North Carolina Hospital to investigate why patients were infected with Stenotrophomonas Maltophilia. Patients and environmental isolates were inspected by pulse-field gel electrophoresis. Furthermore 100 ml water samples were collected in sterile containers and tested using standard methods. In addition the aerators which have stainless steel wire mesh were removed and swab by placing them in 5ml to 10 ml of trypticase soy broth.

A substantial environmental appraisal was carried out. They found that faucet aerators have S. Maltophilia and concluded that low levels of contamination in the water supply system promoted the growth of the bacteria.

On the other hand, Huang and Eason (2007) reported that, faucets aerators and laminar could not enhance the production and increase the concentration of Legionella in a hospital in Taiwan. They built a model that consisted of six faucets: two faucets with aerators, another two faucets with laminar and the two remaining faucets acted as a control. The model was sterilized prior to the commencement of the experiment and the water flowed uniformly through all taps. The duration of the study continued for twenty seven weeks.

500 ml of water samples were gathered from faucets then concentrated to 5 ml via pore filters of 0.22 µm. The aerators and the laminars were also removed. Swabs were collected using BBL culture swab: Becton Dickinson, this was by inserting into the faucets and swiveling it around the interior surface two times clockwise and two times up and down to take away sediment from the tap. Then the culture samples were incubated at 37 C° in a humidified atmosphere for 3- 7 days.

The total number of samples collected was 102 and the result showed that the average concentration of Legionella species was 3,529 cfu/L in the control faucet, 2412 cfu/L in faucets with aerators and 5,912 cfu/L in faucets with the Laminar. Which indicated that, the faucet aerators has no significant impact on Legionella growth compared to the control point and the laminar faucet. Furthermore the Legionella species concentration on the biofilm samples was 530 cfu/L for the control sample , 515 cfu/L in the faucets with aerators and 647 cfu/L in faucets with the Laminar device. The results showed that the aerators have no significant impact on the Legionella promotion.

The average water flow was also checked and found and recorded at 6 L/Min for faucets with aerators, 1.2 L/Min for faucets with Laminar and 11 L/Min for control faucets. At the end Huang and Eason could not prove the hypothesis that installation of the aerator and laminar water flow devices may have promoted the growth of Legionella species in hospitals.

In the light of the above studies it seems that, there is a lack of conducted studies investigating the effect of the faucet aerators on the bacterial growth which may compromise water quality. This research intends to bridge such gab taking in to consideration the U.A.E as a place for the study beside the effect of water pressure on bacterial growth as well as the water flow rate from different types of aerators.

3.2 Selection of Research Method

Despite the fact that, there is no absolute substantial method since all methods have their own advantages and disadvantages. So the topics of the research and researcher awareness of the methodologies are playing a major role in choosing the most suitable methodology for a topic which may be led to minimize the method cons. The researcher plays a key role in assessment of the relationship between the cause and effect in order to back up or reject a hypothesis.

The experimental methodology has many pros as it is considered the appropriate method for quantitative research in order to obtain reliable data about independent variables. (Walker 2005). Beside it is popular approach in scientific researches as it is distinguished by independent and dependent variables, using control samples and focusing on finding the correlations between cause and effect (Groat and Wang 2002).

Another advantage of the experimental method is the role of the control element since the results are compared to the control element. Next advantage is collection of suitable random number of samples in order to reduce bias effect. Beside the previous advantages, using appropriate and accurate tools in the measurements and ability to use software in analyzing the results.

Actually it is worthy to mention that in technical research area the experimental methodology is the most appropriate and trustworthy method for evaluate the cause and effect. The hypothesis of this quantitative research is that Faucet aerators might affect the re-growth of the bacteria and the deterioration of the aerators efficiency. Consequently, the experimental method is the only method applicable in such topic since the total bacteria in water and the water flow rates will be measured which cannot be achieved without experiment. As seen before, previous studies showed that only one method was applied to such research which is the experimental method. So in this research an experimental method was chosen to test the hypothesis.

3.3 Aerators used in the current experiment

In the conducted experiment four types of the aerators were chosen from the local market in U.A.E are described as below:

3.3.1 RST long life aerators

Referred to as (R) in the experiment; this aerator consists of a double inlet filter made of stainless and PVC. The outlet made of stainless steel mesh and there are many layers of mesh filters between the inlet and the outlet see Figure 3.1

Figure 3.1 Aerator type R

According to RST's manufacturer it "can save 40% to 60% of water and energy. It has a sensitive membrane which can diminish the water flow according to pressure. In downstream jet separators the water is accelerated to a high speed and this sucks in significantly more air in comparison to conventional aerators. This air makes the water jet noticeably softer and more even". Also the manufacturer claims that its system is resistant to lime scale build-up and bacteria (RST water saving 2010).

3.3.2 Neoperl type (N)

According to the manufacturer this aerator is in compliances with ASTM B456 which has specification preventing it from corrosion. It also complies with ANS/NSF 61 against toxicity evaluation. Furthermore the water flow via aerators in sink faucets is 2.2 GPM maximum at 60 PSI, this means that it can save 20% to 30% of water use thus it's fittings can provide two LEED points when certifying a building (Neoperl, 1010).Figure 3.2 shows aerator type N which consist of three major parts, Stainless steel casing, PVC casket and the inner par which has many PVC mesh layers.

Figure 3.2 Aerator type N

3.3.3 Kistenmacher (K)

Some parts of this type of aerator are made from PVC and other parts made of stainless steel as shown in figure 3.3. The casing inlet mesh and washer are made from rubber while the outlet mesh and casing are made from stainless steel. (Kistenmacher Germany)

Figure 3.3 Aerator type K

3.3.4 Pressure Compensating aerator (PCA) spray (P)

According to Neoperl's manufacturer this type is recommended in locations with low flow conditions. It is unbreakable single piece insert which provided non-splashing and non-aerated spray as per Figure 3.4. The inlet and outlet mesh are made from plastic while the casing is made from stainless steel. Spray Faucets are suitable for hand washing and their uses is restricted to small domestic hand basins since its flows best at about 1.8 Liters/ Min (Roaf 2007). This type is currently installed in Dubai International Academic City (DIAC) washrooms.

Figure 3.4 Aerator type P

The Advantage of this type is that, it has a potential to produce a constant water flow rate regardless of pressure fluctuations (see Figure 3.5)

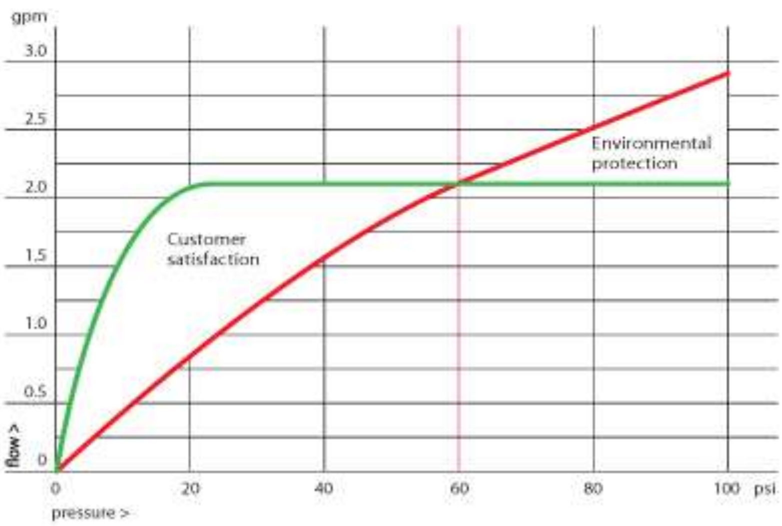

Figure 3.5 Pressure Compensating aerator (Neoperl)

3.4 Description of DIAC washrooms

Dubai international Academic city established in 2007 is located on 18 million square feet of land situated near Oasis City in Dubai. Currently it compromises three phases; each phase contains four academic buildings. Phase three which compromises buildings 9, 10, 11 and 12 was certified as LEED silver (Al Mashni 2009).

The water supply system consists of reinforced underground water tanks which receive water from Dubai Electricity and Water Authority (DEWA). The water is pumped from the tank through 150 mm PVC pipe into 100 mm PR. PVC pipes are located inside shafts then the pipes branched in to the washrooms. The branch Pipes made from PR. PVC pipe of 16 mm to 25 mm for cold water and 20 mm PRP pipe for hot water (see figure A.1, A.2 in the appendix A). The washrooms are located on each floor between the buildings. Some washrooms have five washbasins and other have seven. (See the photo A.3 in the appendix A).

According to Dubai Municipality (D.M) regulations, all medical health care and commercial centers should periodically carryout water sampling. Tests and be reported to them. If the result exceeds the threshold level set by D.M then water treatment should be done next retested. According to DIAC facility management, this practice is not applied in DIAC. This condition made DIAC proper choice to conduct the experiment without any interference beside it is easy to access it in any time.

3.5 Experimental procedures

The most important feature of the experimental method, is finding the relationship between independent and dependent variables in order to prove the hypothesis. In this study water pressure and aerator types are considered as independent variables while bacterial concentration and water flow are considered to be dependent variables. Beside parameters such as water temperature and pH levels along with the air temperature inside the washrooms were recorded.

A request through British University in Dubai was sent to DIAC management to get permission to conduct the experiment. A meeting with the facility management department was conducted to understand their practice in the maintenance of the water supply systems during the meeting they revealed that; usually every six month there is maintenance for the existing aerators. Accordingly the next maintenance will be conducted after six months thus the experiment results would not be compromised. In addition they mentioned that no treatment could be carried out on DIAC campus. Furthermore, water tank location and water supply pipe type and size were obtained.

The wash rooms under study were chosen on a condition that they should be on a regular basis used by most consumers in order to avoid bias which could resulted from stagnation of the water in the aerators. Consequently washrooms on the ground floor between buildings 9-10, 10-11 and 11-12. In addition to, washroom on fifth floor between buildings 9-10 were chosen. The old plumbing fixtures of the washbasins were dismantled and four different types of the aerators (total 16 no.) were labeled and sterilized using Alcohol and installed.

Three different water pressure were set; 2.5 water bar on 5^{th} floor between buildings 9-10, 2 bar on ground floor between buildings 9-10 and 11-12 and 1.5 bar on ground floor between buildings 10-11. Indeed it was impossible to set water pressure for more than 2.5 bar due to the facility management recommendations.

pH meter, stopwatch, graduate cylinder, thermometer and 500 ml sterile water containers were used for the field experiment (see Figure 3.6) and D.M's lab was used to reform the HPC test . In order to record the effect of the faucet aerators on bacterial re-growth and flow rate three control faucets (without aerators) were assigned in the three different pressure areas.

Figure 3.6 Tools used in Field Measurements

The water sampling and flow rate test were conducted every four weeks; these tests continued from October 2010 until March 2011. At the end of the study one hundred twenty water samples were collected in addition to measure flow rates from the aerators.

In the first cycle, old aerators were dismantled, sterilized by emerging them in hydroxide alcohol and replaced by the cleaned one. All water valves related to faucets aerators under the study were checked that they were fully opened. Water flow was tested by filling up graded bottle to 1000 ml: the time it took for this to happen was recorded. The flow test was repeated three times for each faucet then, the average was computed. 500 ml of water samples were labeled and collected from the faucet aerators, control points and water tank.

The Temperature of the water from the faucet aerator and water tank were measured using a thermometer. Air temperature inside the washrooms and pH of the water from the tank as well as the aerators were also recorded. The aforementioned steps were repeated for all cycles.

Failure to follow proper techniques for collection and handling the samples may lead to the results becoming compromised, so all samples and tests were performed early morning at 5:30 a m. At such time no consumers were in the campus that means that the water pressure was stable on all faucets thus accurate results may be recorded. All samples were transferred to D.M lab before 7:30 am in order to avoid time delays between collection and analysis of the samples.

D.M laboratory followed standard methods for the examination of water and waste water. They followed the Pour plate method for the HPC test which included sample preparation, media and incubation. All equipment used in the test which included the oven, the incubator and the colony counter were calibrated according to the standard. In this method, the techniques are very simple since it is suitable for any volume of samples or diluted samples. In D.M's lab, the work area was disinfected and well lighted with a suitable working environment for staff to handle the equipment and the samples properly (see Fig 3.7).

The samples were marked and information which including time, date sample reference number and dilution percentage of one to ten was recorded. All plates or glass used in the tests were pre-sterilized prior the examinations. In each cycle, the following procedures were followed: each water sample was divided in to two samples of 10 ml on each plate and diluted by adding 90 ml of pre-prepared peptone water. Pre-prepared media (tryptone, glucose yeast agar) autoclaved at 121 C$^\circ$ for 15 min. then, cooled until 47 C$^\circ$ finally added to the diluted sample and mixed thoroughly by rotating the plate clockwise then counterclockwise.

After few minutes, the media had solidified and the plates were kept in the oven under 36 C$^\circ$ over 48 hrs. The plates of each sample were subjected to counting via colony counter (Fig 3-8). The counted number was multiplied by 10 in order to take into consideration the dilution factor. If the results of the two plates were relatively the same, the average counted number of the two plates was reported.

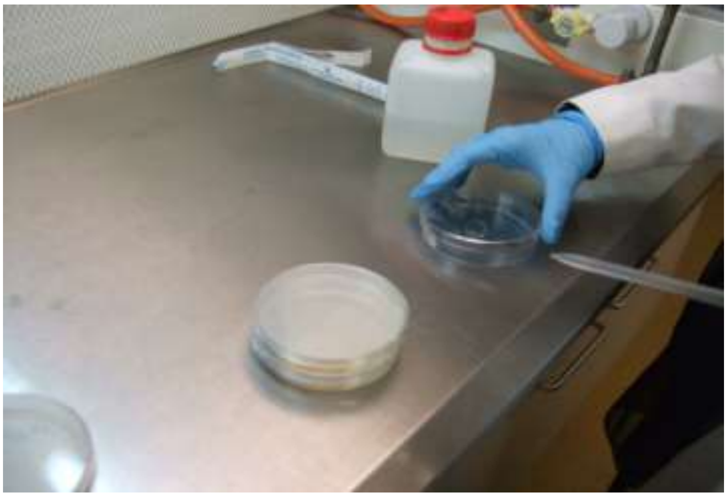

Fig 3.7 Suitable working environment in D.M lab for HPC test

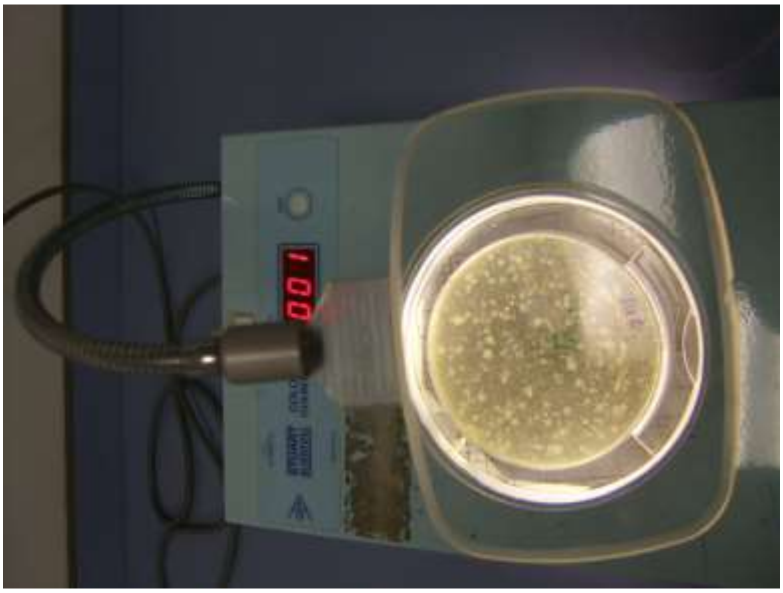

Fig 3.8 Colony Counter

It is worthy to mention that the number of 120 water samples over the six month duration was relatively higher than the number of samples collected by Huang and E., 2007 which was 102 water samples and relatively less than the samples collected by Wang et al 2009 which was 162 water samples. Beside that the duration of my study was six months which was longer than the duration of study conducted by Wang et al 2009, and match with a research conducted by Huang and E. 2007.

3.6 Ethical issues:

It is very important to be mention Ethical issue in the research. At the beginning of the research permission from DIAC management was obtained. Beside that acknowledgment of the location of water samples was not disclosed to D.M since results exceeded threshold set by D.M which might affect the reputation of DIAC. Furthermore, the name of technical man from DEWA who provide data about chlorination of the water was kept as anonymous based on his request. Finally all results were reported to DIAC management for their action.

3.7 limitations of the study:

Generally speaking, although the experimental method was the most reliable approach for the research, there were many weak points related to it. For instance; its effectiveness may not reflected the actual real condition incase of small population samples. Another weakness point is some biases which may affects the results as will be explained below (Groat and Wang 2002).

It is essential to indicate and analyze limitations and problems faced during the study which may affect the results of the research and they are illustrated as below:

3.7.1 Limitation

1-The location of the conducted study was in Dubai International Academic city (DIAC). Despite the fact that water was supplied by DEWA, the water quality may vary from place to place since there are many different reservoirs.

2-Due to time constraints, duration of water sampling was 24 weeks only from October to March which meant that the effect of hot weather condition was almost excluded.

3-Due to Financial restriction the number of faucet aerators were sixteen. Accordingly, the water samples number was 120 which limited the conclusion that could be drawn. Beside the water test was limited to HPC test only.

4-Bias in the experiment may be resulted in counting of the HPC bacteria since, the counting process depends on the person who is counting the bacteria which may be affected by human error.

Chapter 4 -Results

4.1 Introduction

During the twenty seven weeks, 120 water samples were collected from the faucets and the water tank in DIAC, in order to investigate the effect of the faucets aerators on bacterial growth which may affect the water quality. Water flow rate from the faucets with different types of aerators and control points (all in which under different of water pressure) were measured in the field. Parameters such as pH, water Temperature and air temperature inside the washrooms were recorded over the study period. The HPC concentration was measured in the lab. Excel software was used in the statistical analysis. The results are illustrated in the following sections.

4.2 HPC concentration in different types of aerators

Table 4-1 illustrates the variation of HPC concentration in the aerators type P. In cycle two, it declined for type P2, P3 and P4 while increased for type P1. In cycle three the concentration increased sharply from 11,940 cfu/ml to 211,100 cfu/ml for aerator type P3 and slightly decreased for the rest. In cycle four the concentration decreased sharply for all types. In cycle five there was a drop in the concentration for all types. For instantce the HPC decreased from 11,830 cfu/ml to 1615 cfu/ml for aerator P1. In cycle six the HPC concentration increased noticeably in all types. Considering the average values for each type, the concentration decreased from 18,773 cfu/ml in cycle one to 14,623 cfu/ml in cycle two then increased to 16,843 cfu/ml in cycle three. Next it continued to decrease dramatically in cycle four and five to 1561 cfu/ml.

Then rose up dramatically to 4,900 cfu/ml. The fluctuations presents in Fig 1-4.

Table 4.1 HPC concentration in aerators type P

Cycle No	P1	P2	P3	P4	Average
1	12,510	23,660	18,550	20,370	18,773
2	17,780	15,610	11,940	13,160	14,623
3	17,640	16,310	21,100	12,320	16,843
4	11,380	11,760	9,030	4,960	9,395
5	1,615	1,275	1,445	1,910	1,561
6	4,580	4,440	7,790	6,140	4,900

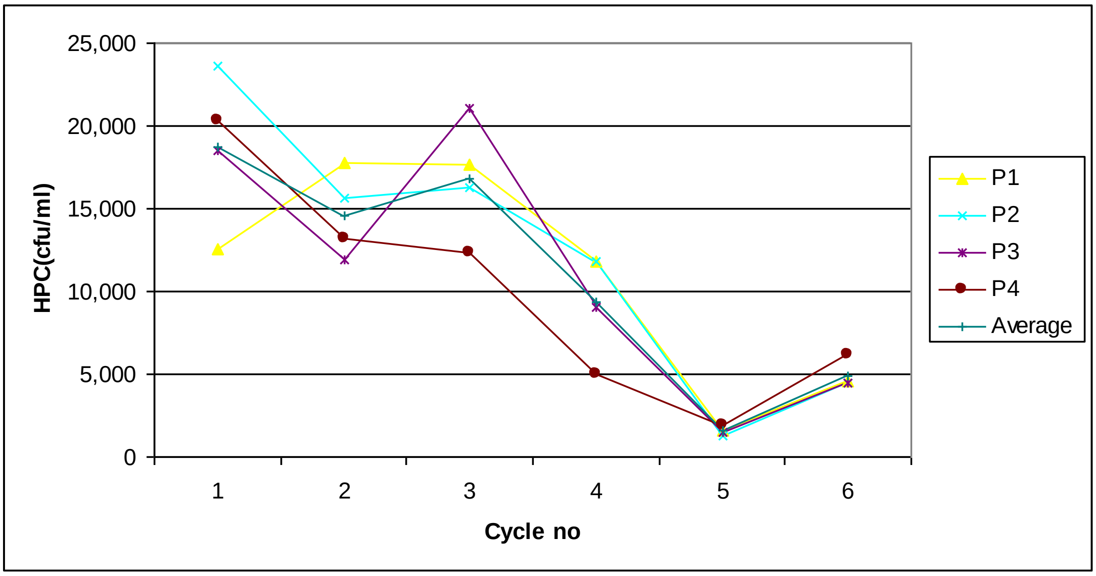

Fig. 4.1 HPC concentrations in aerators type P

Table 4.2 shows the changes of HPC concentrations in aerator type N. In cycle two the concentration sharply decreased in all aerators except in aerator N2 in which the concentration increased from 19,250 cfu/ml to 26,360 cfu/ml. In cycle three the opposite occurred; the concentration increased in all types except N2 in which decreased to 16,590 cfu/ml. In cycle four the concentration decreased in all types N. In cycle Five the HPC dramatically dropped in types N1, N2, and N3 while it dropped slightly in N4. In cycle six the concentration augmented radically in all types except in aerator N4. The average value indicted that a reduction was made in this type from 22,172 cfu/ml in cycle one to 16,222 cfu/ml in cycle two, then increased to 19,872 cfu/ml in cycle three then again decreased to 7,372 cfu/ml in cycle four, then dropped dramatically to 4,043 cfu/ml in cycle five. Then in cycle six it elevated to 5,577 cfu/ml. Figure 4.2 summarizes the changes in the concentrations.

Table 4.2 HPC concentration in aerators type N

Cycle No	N1	N2	N3	N4	Average
1	21,000	19,250	25,060	23,380	22,172
2	13,930	26,360	11,200	13,400	16,222
3	18,700	16,590	19,000	25,200	19,872
4	4,320	6,680	5,960	12,350	7,372
5	1,805	1,750	3,220	9,400	4,043
6	5,480	5,720	4,550	6,560	5,577

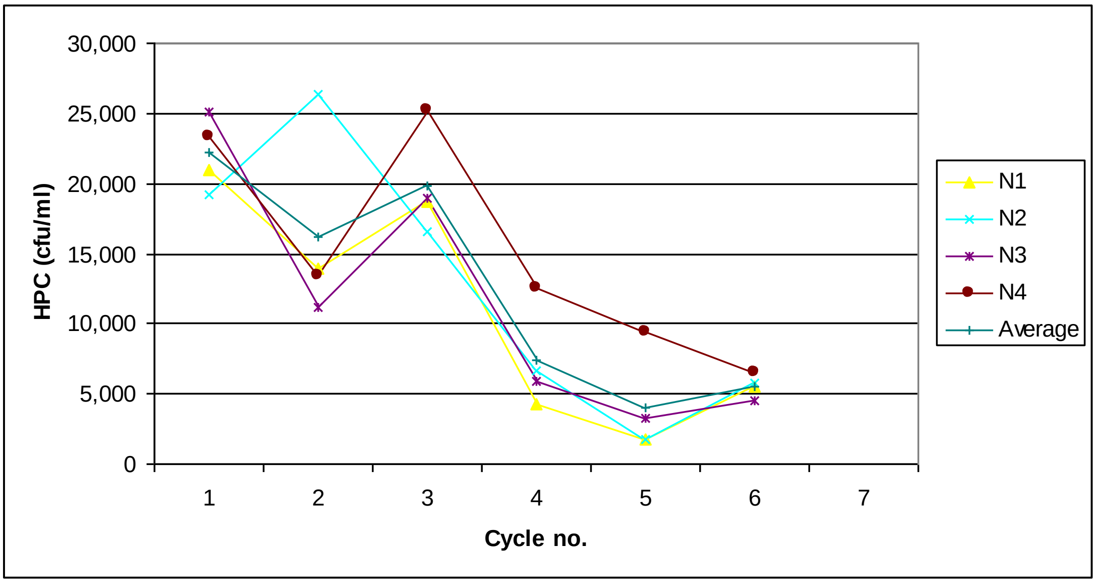

Figure 4.2 HPC concentrations in aerator type N

Table 4.3 displays changes in HPC concentrations in aerator type R. In cycle two the concentrations were slightly reduced in all aerators, then in cycle three the concentration further decreased in all aerators except for R1 in which the concentration sharply increased from 15,400 cfu/ml to 22,300 cfu/ml. In cycle Four the concentration significantly declined in all aerators. In cycle five the HPC concentration decreased sharply in all aerators type R to level below 2000 cfu/ml. In cycle six the concentration sharply increased in all types. Considering the average concentrations for all aerator type R the result indicated a decrease in HPC concentration during all cycles except in cycle six in which the concentration increased as shown in Figure 4.3

Table 4.3 HPC concentration in aerators type R

Cycle No	R1	R2	R3	R4	Average
1	24,780	22,190	18,410	20,400	21,445
2	15,400	19,320	16,940	17,360	17,255
3	22,330	17,640	15,050	1,7150	18,042

4	10,710	7,030	7,630	6,280	7,912
5	1,585	1,745	1,460	1,620	1,677
6	5,040	9,400	4,960	5,300	6,175

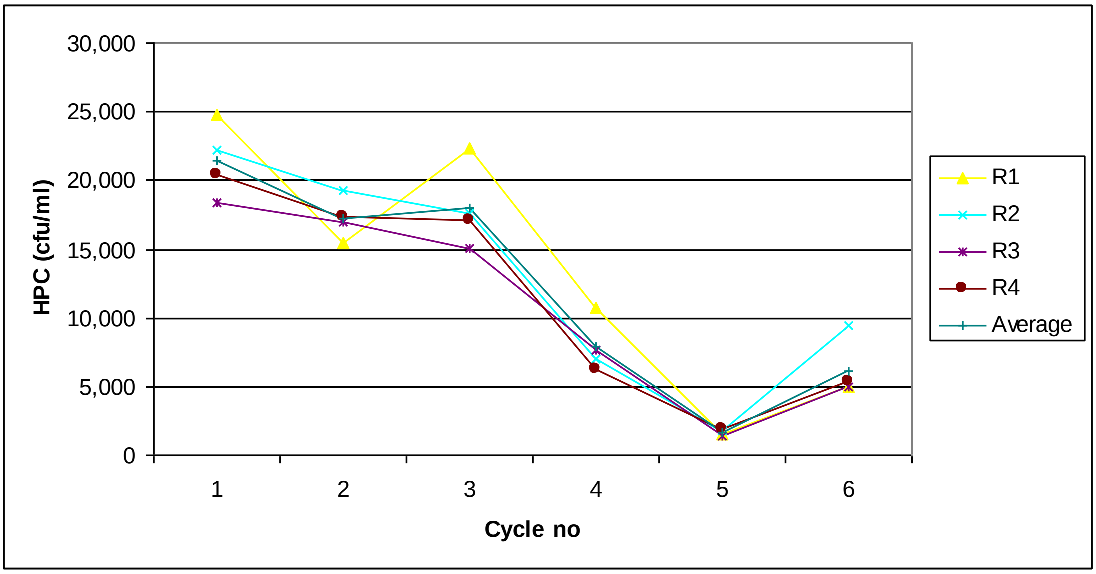

Fig 4.3 HPC concentrations in aerators type R

Table 4.4 illustrates HPC concentrations in aerators type K. In cycle two the concentrations decreased in all aerators type K. In cycle three the concentration decreased in all aerators except in K1 in which the concentration extremely increased from 9,170 cfu/ml to 24,000 cfu/ml. In cycle four the concentrations greatly declined in all aerators. In cycle five a further reduction occurred in all aerators type K and reached to level below 2000 cfu/ml. In cycle six the HPC concentration notably increased in all types. Considering the average value of the concentrations the results showed that the concentration decreased in cycle two then increased in cycle three and again sharply decreased in cycle four and five. Then the average concentration increased sharply in cycle six. Figure 4.4 demonstrates the results.

Table 4.4 HPC concentration in aerators type K

Cycle No	K1	K2	K3	K4	Average
1	22,400	28,420	21,350	22,540	23,677
2	8,170	21,000	19,250	10,780	15,050
3	24,000	12,400	14,800	18,100	15,050
4	10,780	6,700	1,425	8,610	6,879
5	1,820	1,345	1,285	2,115	1,641
6	6,020	5,640	5,420	8,080	6,290

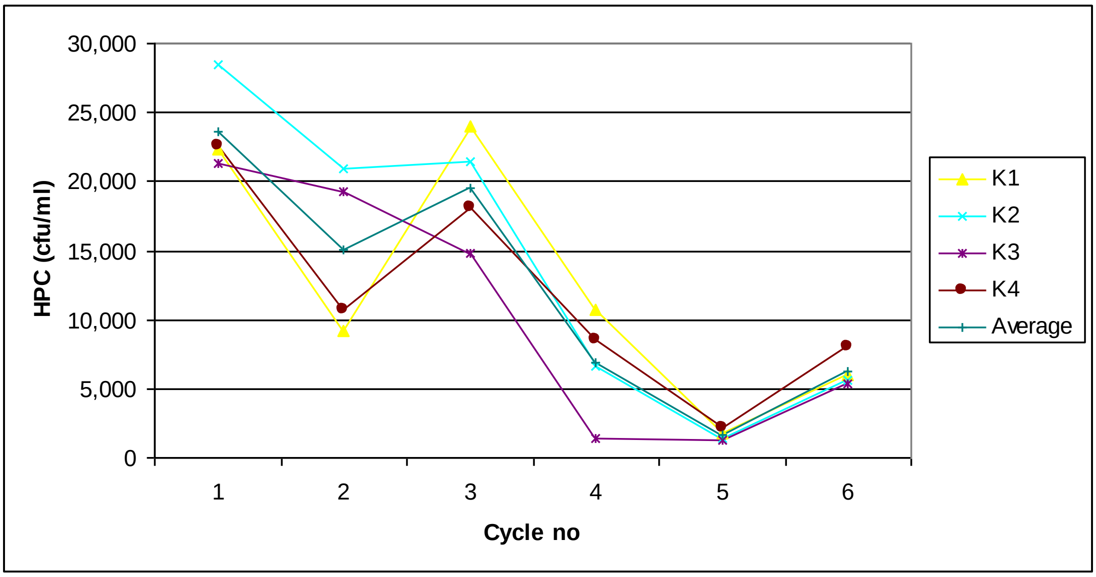

Figure 4.4 HPC concentrations in aerators type K

4.3 HPC concentrations in Faucets under different water pressure

Water pressure has an impact on the water flow which may affect the re-growth of bacteria in the water. In the following section the HPC concentrations are illustrated taking into consideration different water pressure values.

4.3.1 HPC concentrations in Faucets under 2 Bar water pressure

Table 4.5 illustrates the average values of HPC concentrations in the aerators and control point (Faucet without aerator) under 2 bar water pressure. For aerators type P the concentrations increased in cycle two then somewhat decreased in cycle three and sharply decreased in cycle four then notably decreased from 11,830 cfu/ml in cycle four to 1,615 cfu/ml in cycle five. Then in cycle six the concentration dramatically increased to 4,580 cfu/ml. In aerators type K and R the concentrations decreased in cycle two then increased in cycle three and decreased again in cycle four and five to reach a level below 2000 cfu/ml in cycle five. Then again increased sharply to 6000cfu/ml in cycle six. For aerator type N the concentration slightly decreased in cycle two then sharply decreased in cycles three, four and five. Next in cycle six the HPC concentration increased. In the control point the concentration decreased in cycle two then increased in cycle three and decreased again in cycle four then dropped extremely from 10,780 cfu/ml in cycle four to 1,550 cfu/ml in cycle five. Then the concentration increased to 5520 cfu/ml in cycle six. Figure 4.5 shows the variations in average concentrations in aerators, control point under 2 bar water pressure and the water tank.

Table 4.5 HPC concentration in aerators under 2 bar water pressure

Cycle No	P	K	R	N	C1
1	12510	22400	23485	20125	24640
2	17780	9170	17360	20145	9520
3	17640	24000	19985	17645	18620
4	11830	10780	8870	5500	10780
5	1615	1820	1665	1777	1550
6	4,580	6,020	7,220	5,600	5,520

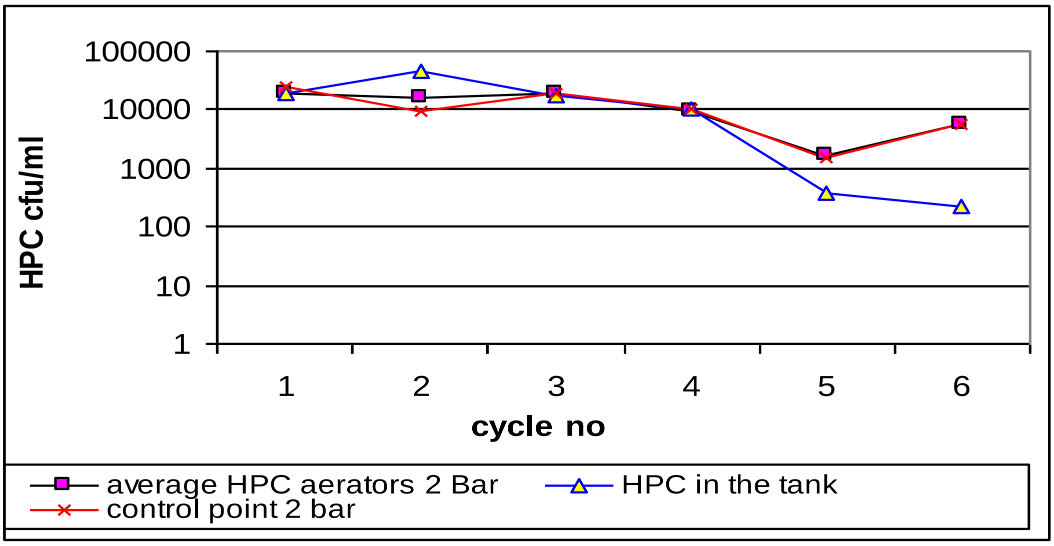

Figure 4.5 Average HPC concentrations in aerators, control point under 2 Bar water pressure and the water tank

4.3.2 HPC concentrations in Faucets under 2.5 bar water pressure

Table 4-6 demonstrates the HPC concentrations in different aerators and control points under 2.5 bars of water pressure. For all type of the aerators the concentrations decreased in cycle two. In cycle three the concentration decreased for aerators type R while it increased on the other type of the aerators as well as the control point. In cycle four and five the concentration significantly decreased in all aerators and control point. In cycle six the concentrations again increased in all faucets. Figure 4.6 presents the changes on the concentrations in aerators, control point and water tank.

Table 4.6 HPC concentration in faucets under 2.5 bar water pressure

Cycle No	P	K	R	N	C
1	21,105	21,945	18,410	25,060	24,760
2	13,775	15,015	16,940	11,200	17,430
3	18,705	16,450	15,050	19,000	18,675
4	10,395	5,017	7,630	5,960	8,190
5	1,360	1,700	1,460	3,220	1,360
6	4,440	6.750	4,960	4,550	5,350

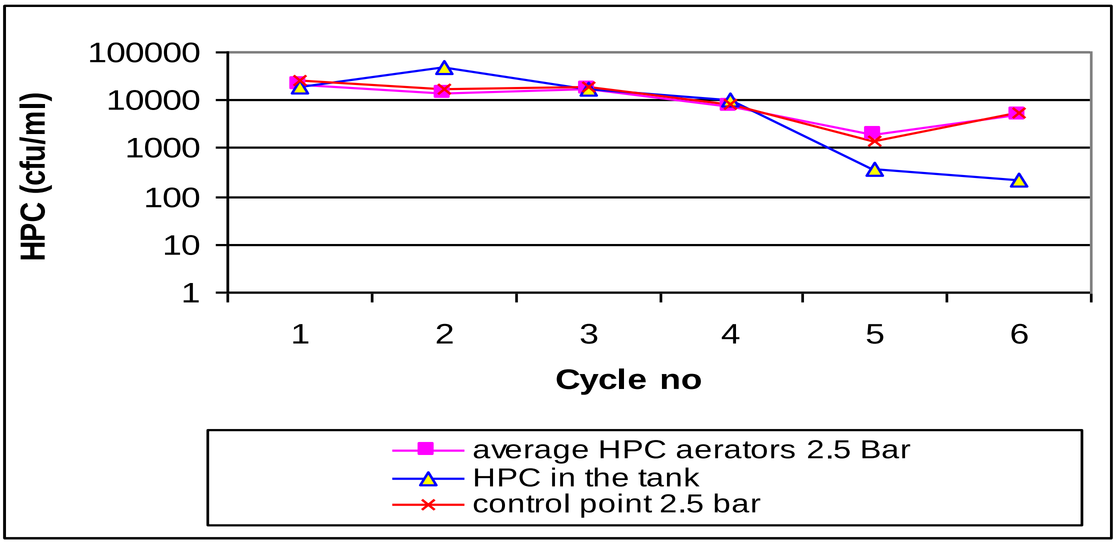

Figure 4-6 Average HPC concentration in aerators and control point under 2.5 Bar water pressure and the water tank

4.3.3 **HPC concentrations in Faucets under 1.5 water pressure**

Table 4.7 presents the HPC concentrations on deferent type of aerators under water pressure of 1.5 water Bar. In cycle two the concentrations decreased for all types of the aerators as well as the control point. In cycle three the concentrations in all types of the aerators and the control point slightly varied from the concentration in cycle two except in aerators type N in which the concentrations increased sharply. In cycles four and five the concentrations declined in all aerators and control point. In cycle six the concentration sharply elevated in all types. Figure 4.7 illustrates the variations in the average HPC concentrations the aerators, control point and the water tank.

Table 4.7 HPC concentration in faucets under 1.5 bar water pressure

Cycle No	P	K	R	N	C
1	23,660	28,420	20,400	23,380	31,080
2	15,610	21,000	17,360	13,400	16,590
3	16,310	21,400	17,150	25,200	17,360
4	11,760	6,700	6,280	12,530	1,675
5	1,275	1,345	1,920	9,400	1,420
6	4,440	5,640	5,300	6,560	4,430

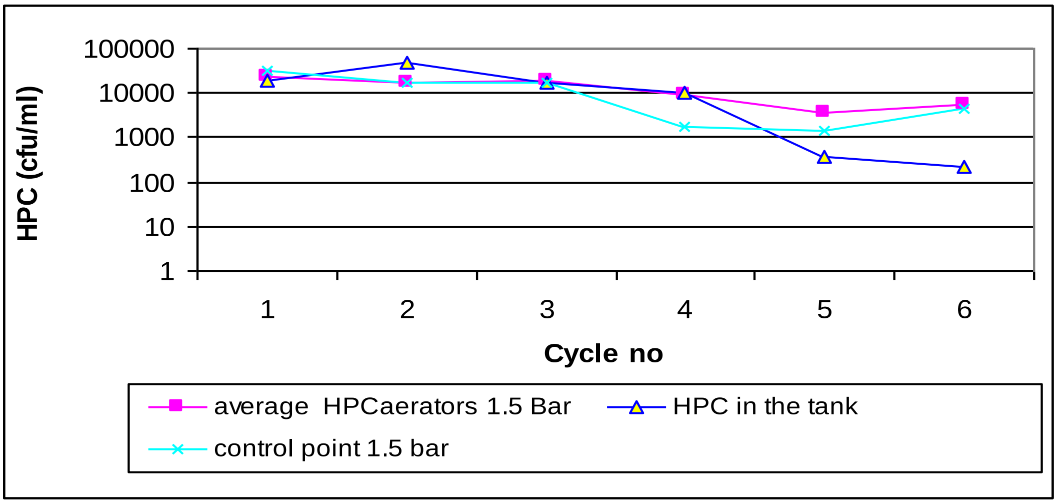

Figure 4.7 Average HPC concentrations in aerators ,control point under 1.5 Bar water pressure and the water tank

Table 4.8 shows the changes in HPC concentrations during the cycles in the control points as well as in the DIAC water tank phase three which received the water from DEWA. In cycle Two the concentrations decreased in all control points although the concentration sharply increased in the water tank. In cycle three the concentrations increased in all control points but it decreased in the tank. In cycle four the concentration decreased in all types however, the concentrations in the control points remained under the concentration level in the tank. In cycle five the concentration decreased sharply in all control points as well as in the tank but the concentration in the control points remained higher than the concentration in the tank. In cycle six the concentration in the control points increased however the concentration in the tank decreased. Figure 4.9 illustrates the changes.

Table 4.8 HPC concentration in the control points and water tank

Cycle No	C1	C2	C3	Water tank
1	24,640	24,760	31,080	19,460
2	9,520	17,430	16,590	46,000
3	18,620	18,675	17,360	17,500
4	10,780	8,190	1,675	10,710
5	1,550	1,360	1,420	385
6	5,520	5,350	4,430	230

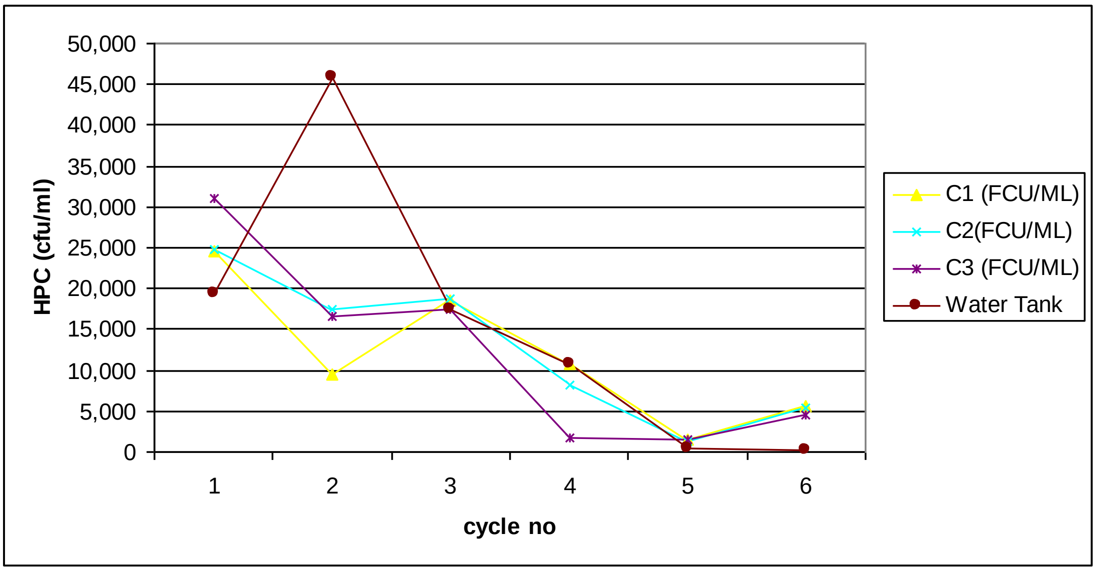

Fig 4.8 HPC concentrations in the control points and the water tank

An investigation was conducted by visiting the Mushrif reservoirs (the main water storage which consist of four reservoirs supplied the water to DIAC). The technician highlighted that in September 2010, there was a breakdown in the vacuum regulator which is used in chlorination of the water prior to it entering the reservoirs. Consequently, there was no chlorination provided for phase one and three until 14th of December 2010. On daily basis 120 water samples were randomly collected from different points in the water supplied system in Dubai and tested via total coliform and E.coli. Based on the results instructions were given to a team add chlorination dosage using calcium hypochlorite with 0.1 mg/l to 0.3 mg/L after 3 pm. Due to aforementioned concern the percentage of the HPC in the aerators under different water pressure values relative to HPC in the DIAC water tank are highlighted in the following section.

4.4 Percentage of HPC of aerators under different water pressure relative to HPC in DIAC tank

Table 4.9 shows percentages of HPC concentrations in aerators under 2 bar water pressure. In cycle one HPC percentage in aerator type P did not exceed the HPC in the water tank while it exceeded the concentration in aerators type K, R and N. In cycle two the percentages were dropped significantly in all types then, again drooped further in cycle three. Next in cycle four the HPC concentration in aerators P and K went beyond the concentration in the water tank while in aerators type R and N it remained below the level. In cycle five the concentration in all type jumped dramatically beyond the tank concentration. In cycle six the percentage of the concentration inflated in all aerators in respect to water tank concentration. Figure 4.9 demonstrates the variations in the percentages.

Table 4.9 Percentage of HPC in aerators under 2 bar respect to HPC concentration in the tank

Cycle no	% in (P)	% in (K)	% in (R)	% in (N)
1	64.29	115.11	121	103
2	37.85	19.52	37	43
3	100.8	137.14	114	101
4	110.46	100.65	83	51.5

5	419.48	402.6	432	461.69
6	1991	2617	3139	2434

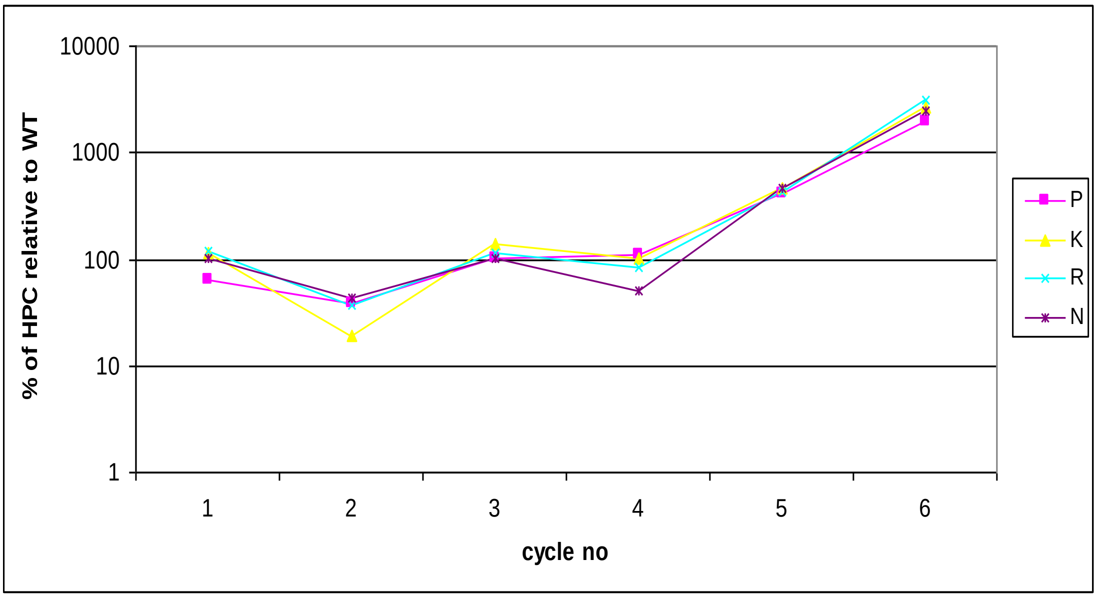

Figure 4.9 Percentage of HPC in aerators under 2 bar respect to HPC concentration in the tank.

Table 4.10 presents the HPC percentage in different aerators under 2.5 water bar with respect to the HPC in the water tank. In cycle one the percentage of HPC concentration in aerator type N and K exceeded the concentration of HPC in the tank. In cycle two the percentages of HPC in all aerators were significantly below the concentration in the tank. In cycle three the concentration in type N was above the concentration in the tank. In cycle four the concentrations in all aerators were below the concentration in the tank. In cycle five and six the concentration in all aerators was significantly higher than the concentration in the tank.

Figure 4.10 shows the variations in the percentage of HPC in the aerators with respect to percentage in the tank.

Table 4.10 Percentage of HPC in aerators under 2.5 bar respect to HPC concentration in the tank

Cycle No	% in P	% in K	% in R	% in N
1	100	113	95	129
2	27	32	36	24
3	95	94	86	109
4	65	47	71	56
5	436	442	379	837
6	2300	2935	2157	1978

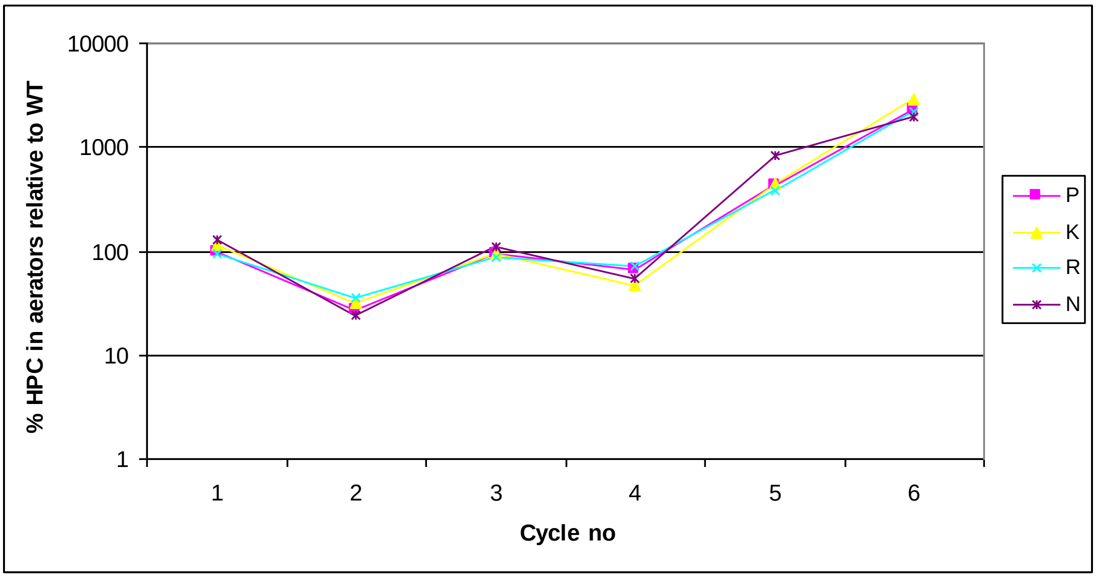

Figure 4.10 Percentage of HPC in aerators under 2.5 bar respect to HPC concentration in the tank

Table 4.11 shows percentage of HPC concentration in aerators under pressure of 1.5 water bar with respect to HPC in the water tank. In cycle one the percentage in all aerators exceeded the same of the water tank. In cycle two there was a reduction in the percentage in all aerators. Next in cycle three the percentage increased again. In cycle four the trend of percentage increased in aerators P and N while it remained below the water tank HPC level in aerator K and R. In cycle five and six the HPC percentage in all aerators exceeded the HPC percentage of the tank. Figure 4.11 displays the variations in the percentages.

Table 4.11 Percentage of HPC in aerators under 1.5 bar respect to HPC concentration in the tank

Cycle no	% in (P)	% in (K)	% in (R)	% in (N)
1	121.58	146.04	104.83	120.14
2	33.23	44.71	36.96	28.53
3	93.2	122.29	98	144
4	109.8	62.56	58.64	117
5	331.17	349.35	498.7	2441
6	1930	2452	2304	2852

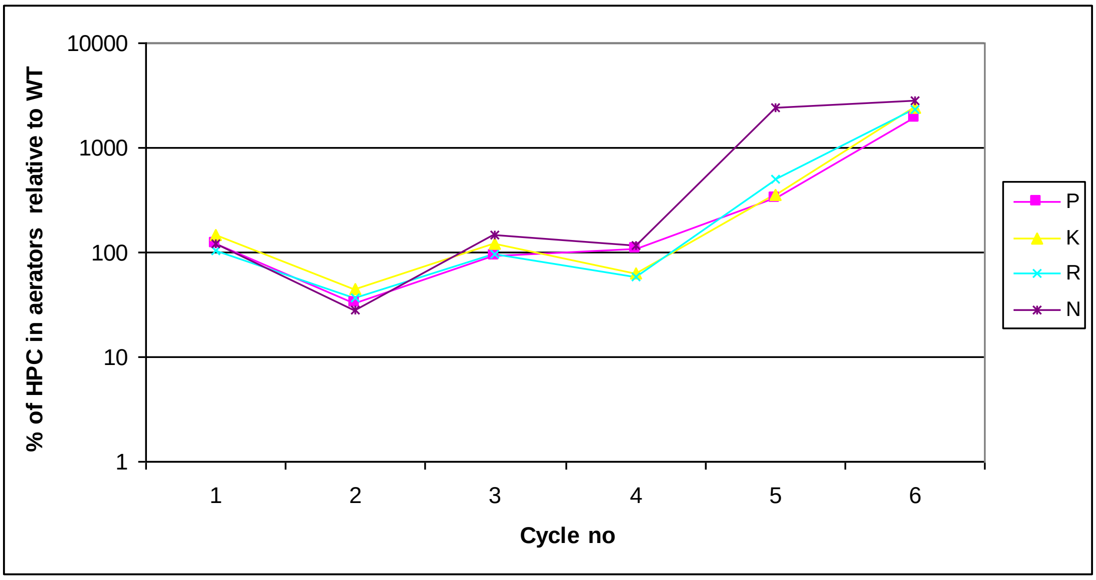

Figure 4.11 Percentage of HPC in aerators under 1.5 bar respect to HPC concentration in the tank

Figure 4.12 summarizes the average HPC concentrations in aerators under different water pressure and HPC in the water tank.

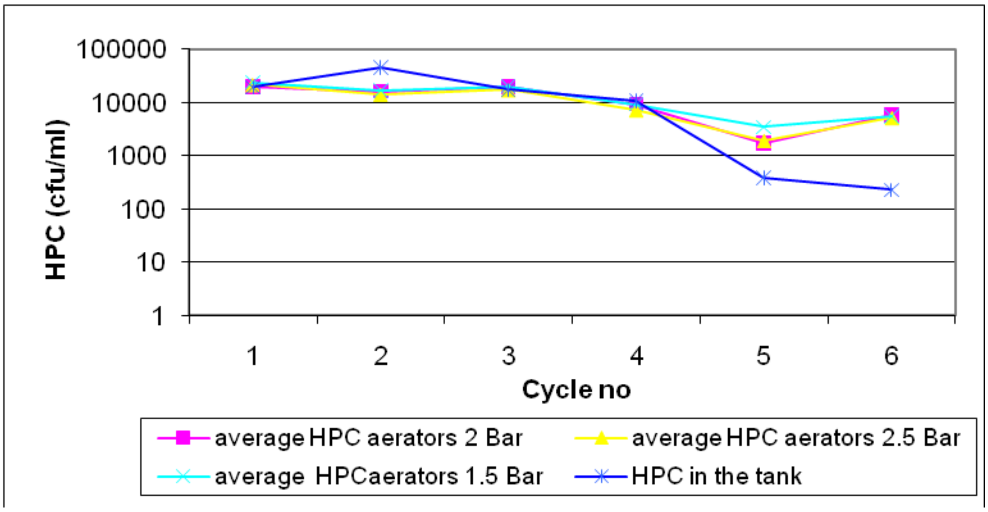

Figure 4.12 average HPC concentrations in aerators under different water pressure and water tank.

As seen in previous table and figures that, all faucets with or without aerators were contaminated so to understand the effect of the aerators the difference in HPC values in the aerators (regardless of their type) and the HPC in the control point are demonstrated in Table 4.12. In aerators under 2 bar water pressure seems to have more HPC than the control point under the same pressure in cycle 2, 3, 5 and six however the opposite occurred in cycle 1 and 4. In aerators under 2.5 water pressure, the HPC concentration in the control point was more than HPC in the aerators except for cycle five. In aerators under 1.5 water pressure the concentrations in the aerators were more than the HPC in the control points except in cycle one only. These differences are illustrated in Figure 4.13

Table 4.12 The HPC difference between the aerators under different water pressure and the control points

Cycle No	ΔHPC in aerators under 2 Bar and control point	ΔHPC in aerators under 2.5 Bar and control point	ΔHPC in aerators under 1.5 Bar and control point
1	-5,010	-3,130	-7,115
2	6,593	-3,197	253
3	1,197	-1,373	2,655
4	-1,535	-939	7,642
5	169	575	2,065
6	335	-175	1,055

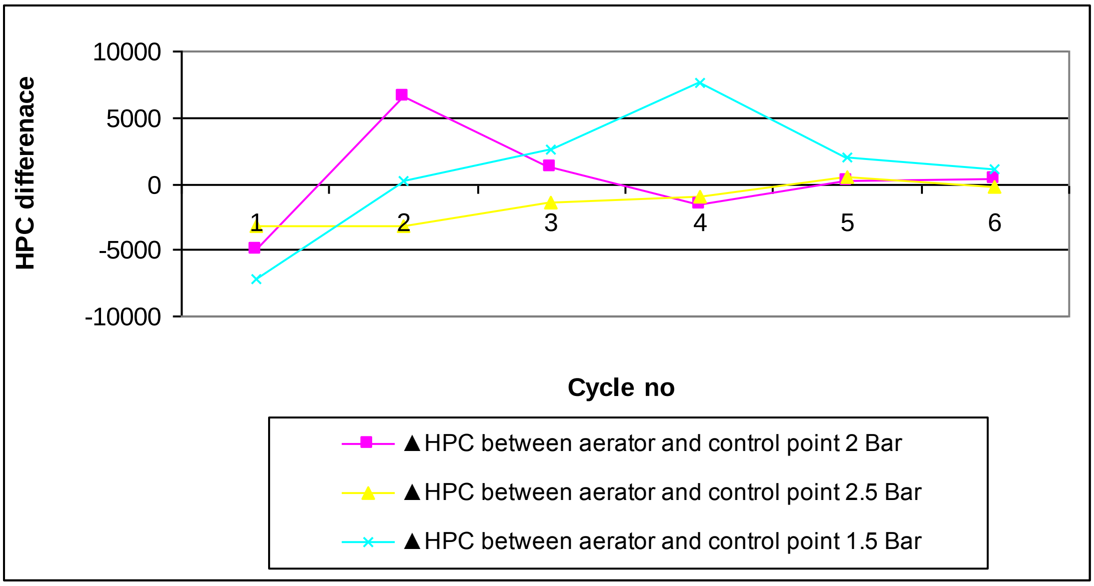

Figure 4.13 differences in HPC between aerators and control points.

4.5 Water Parameters from faucets under different water pressures

Table 4.13 presents the parameters under which different water pressures measured during the six cycles in the field. This included water's temperature, air's temperature and the pH of the water. Also water temperature and pH of the DIAC water tank. It is noted that that the water temperature for the water tank was higher than the water temperature from the faucets under water pressure. In addition it is noted that there was a reduction in the water temperature as well as the air temperature in the tank area from cycle to cycle. Furthermore the pH of the water tank was increased from 7.9 in cycle one to 8.9 in cycle six. Figure 4.14 illustrates the average variations in the pH from cycle to cycle in the water tank as well as the aerators since it was noted that no significant difference in pH values for different aerators.

Table 4.13 Parameters for water in different water pressure and water tank

Cycle no	water pressure 2.5 Bar			water pressure 2 Bar			water pressure 1.5 Bar			Water tank		
	Wt C°	At C°	pH	Wt C°	At C°	pH	Wt C°	At C°	pH	Wt C°	At C°	pH
1	35	23	7.9	29	24	8.1	26	19	8.3	36	36	7.9
2	25	24	8.1	24	19	8	22	20	8.1	36	24	7.9
3	22	20	8.5	21	19	8.5	21	18	8.6	32	17	8.3
4	23	21	8.7	24	19	8.3	20	18	8.3	31	11	8.6
5	23	22	8.7	25	20	8.6	21	20	8.7	31	12	8.6
6	23	20	8.7	23	19	8.7	22	19	8.7	31	16	8.9

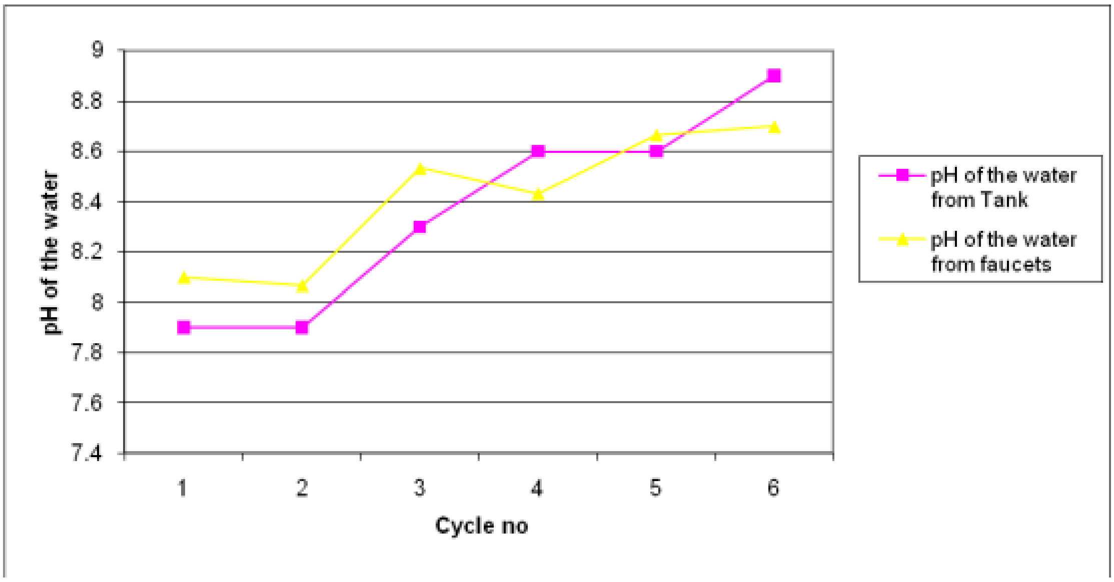

Figure 4.14 pH records over the cycles in the water tank and the faucets

4.6 Water Flow Rates of Faucets Under different Water Pressures

Table 4.14 illustrates the water flow rates expressed in liters per minute, of the different types of aerators as well as the control point, all which were under two Bar water pressure. In cycle one the flow varied from 1.81 L/min for aerator type P, 4.66 L/min for type N, 3.32 L/min for type K, 4.42 L/min for type R, and 5.5 L/min for the control point. It was noted that the flow rate slightly decreased over the cycles. These variations in the flow rates are presented in figure 4.15

Table 4.14 Water flow rate (L/min) of different type of aerators under 2 bar water pressure

Cycle No	Q(P)	Q(N)	Q(K)	Q(R)	Q(C1)
1	1.81	4.66	3.32	4.42	5.55
2	1.8	4.55	3.38	4.4	5.57
3	1.85	4.7	3.42	4.53	5.86

4	1.79	4.61	3.34	4.36	5.92
5	1.74	4.52	3.4	4.41	5.95
6	1.73	4.53	3.29	4.29	5.92

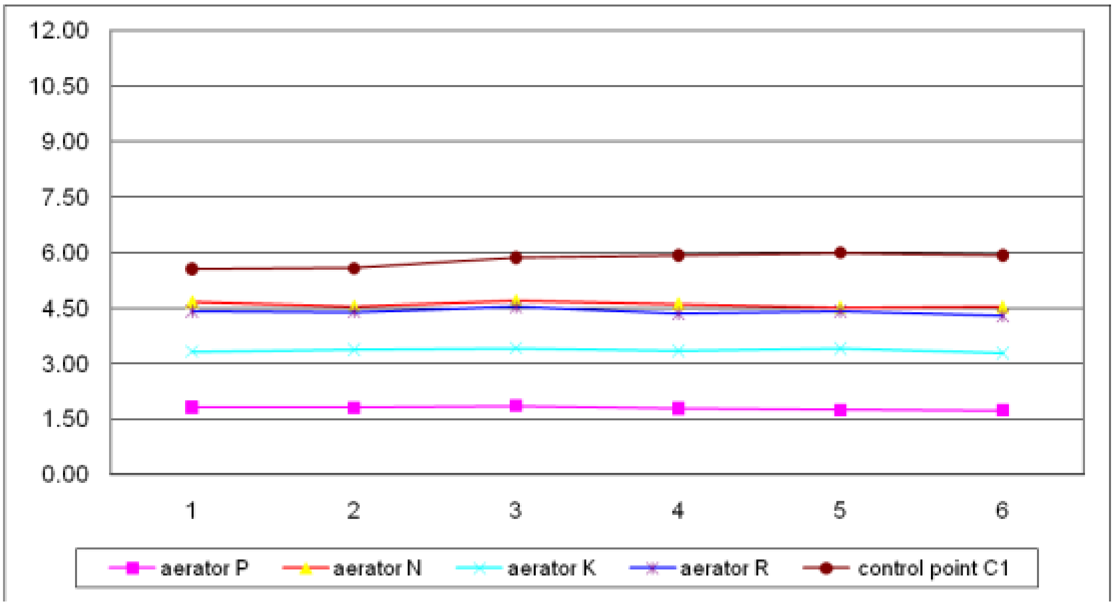

Figure 4.15 Water flow rate of different type of aerators and control point under 2 bar water pressure

Table 4.15 presents the percentage of the water flow rate of the different types of aerators relative to the control point under 2 bar water pressure. It showed that in cycle one the percentage of the flow rate for aerator type P compromised 32.55 % of the water flow relative to the control point, in aerator type N the flow rate was 83.97%, in aerator type K the flow rate was 59.82%, and in aerator type R the flow compromised 79.69 %. In the next cycles, the aerators flow rate percentage almost decreased in all faucets except for the control point which almost remained the same.

Figure 4.16 presents the percentage of the water flow rate of faucets aerator relative to the control point all under 2 bar water pressure.

Table 4.15 percentage of water flow rate relative to control point under 2 bar water pressure

Cycle no.	% of Aerator P	% of Aerator N	% of Aerator K	% of Aerator R
1	32.55	83.97	59.82	79.69
2	32.25	81.62	60.69	78.94
3	31.67	80.19	58.36	77.41
4	30.18	78	56.52	73.67
5	28.94	74.62.	56.71	73.58
6	29.2	75.29	55.94	72.51

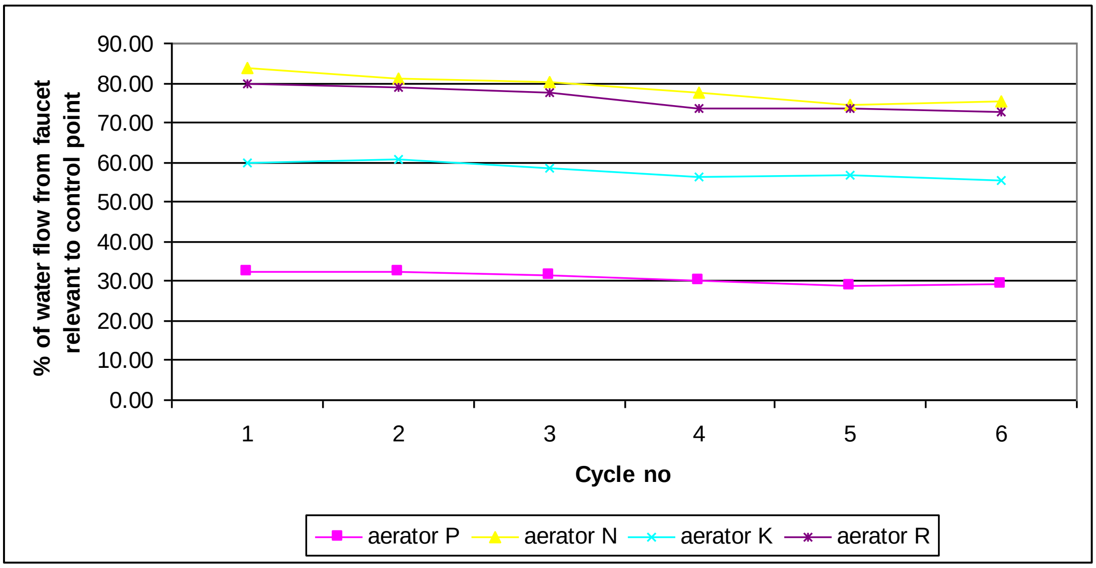

Figure 4.16 percentage of the water flow rate of faucet aerators relative to control point under 2 bar water pressure.

Table 4-16 illustrates the flow rate of different type of aerators and control point under water pressure of 2.5 bar. In cycle one; the flow rate was 1.67 L/min, 4.57 L/min 3.46 L/min, 3.94 L/min and 9.54 L/min for aerators P, N, K, R and C2 respectively. For the next cycles the flow rate slightly varied in each aerator despite the flow rate increased in the control point. At the end of the study the flow rates in all faucets almost the same in respect to first cycle however; the control point the flow rate was slightly increased. Figure 4.17 presents the variation in water flow from cycle to cycle under 2.5 water bar.

Table 4.16 Water flow rate (L/min) of different type of aerators under 2.5 bar water pressure

Cycle No	Q(P)	Q(N)	Q(K)	Q(R)	Q(C1)
1	1.67	4.57	3.46	3.94	9.54
2	1.74	4.65	3.49	4.11	10.6
3	1.69	4.09	3.41	4.17	9.67
4	1.66	4.17	3.41	3.98	10.27
5	1.82	4.58	3.46	4.19	9.83
6	1.82	4.58	3.4	4.11	9.87

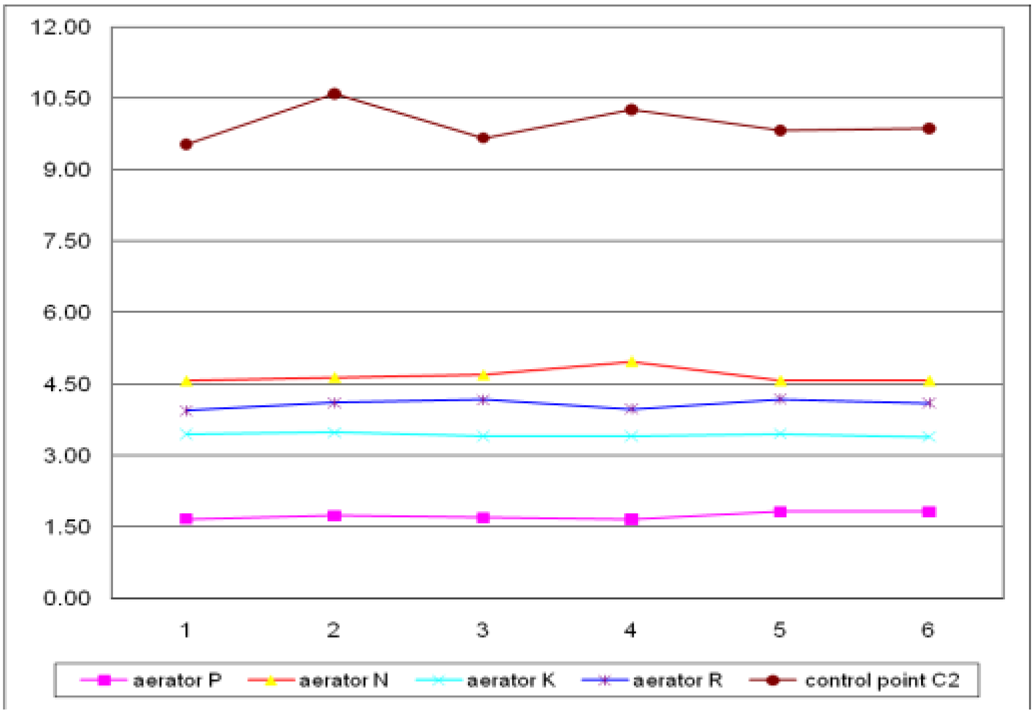

Figure 4.17 Water flow rate of different type of aerators and control point under 2.5 bar water pressure

Table 4.17 shows the percentage of the water flow rates from the different types of aerators in respect to the control point under water pressure of 2.5 bar. In cycle one the percentage of the water flow rate from aerator type P compromised 17.49 % of the control point flow rate, 47.92% for aerator type N, 36.24 % for aerator type K and 41.35 % for aerator type R. In the following cycles the percentage almost decreased. Figure 4.18 presents the percentage of water flow rate from faucets aerators relative to control point under 2,5 bar water pressure

Table 4.17 percentage of water flow rate relative to control point under 2.5 bar water pressure

Cycle no.	% of Aerator P	% of Aerator N	% of Aerator K	% of Aerator R
1	17.49	47.92	36.24	41.35
2	16.4	43.82	32.93	38.79

3	17.51	48.56	35.29	43.15
4	16.18	48.52	33.25	38.76
5	18.51	46.57	35.21	42.6
6	18.48	46.4	34.44	41.62

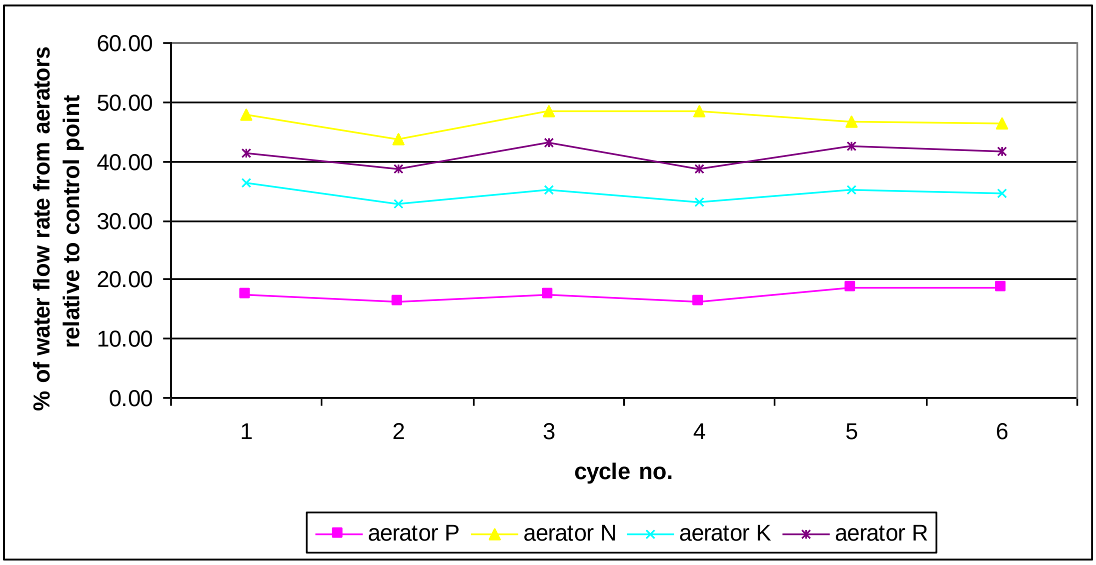

Figure 4.18 Percentage of water flow rate of faucet aerators relative to control point under 2.5 water bar

Table 4.18 displays the water flow rates of the different types of aerators and control point under water pressure of 1.5 bar. In cycle one the flow rate was 2.03 L/min, 3.23 L/min, 2.62 L/min and 2.91 L/min for aerators P, N, K, and R respectively. On the other hand the flow rate of the control point was 4.33 L/min. Figure 4.19 presents the changes in flow rate of the aerators over the cycle period. It shows a decrease in the flow rate from cycle to cycle although the flow rate from the control point is increased.

Table 4.18 Water flow rate (L/min) of different type of aerators under 1.5 bar water pressure

Cycle No	Q(P)	Q(N)	Q(K)	Q(R)	Q(C1)
1	2.03	3.23	2.62	2.91	4.33
2	1.88	3.16	2.63	2.92	4.4
3	1.95	3.05	2.63	2.88	4.6
4	1.84	3.09	2.66	2.93	4.48
5	1.83	3.08	2.6	2.94	4.53
6	1.76	2.95	2.56	2.84	4.48

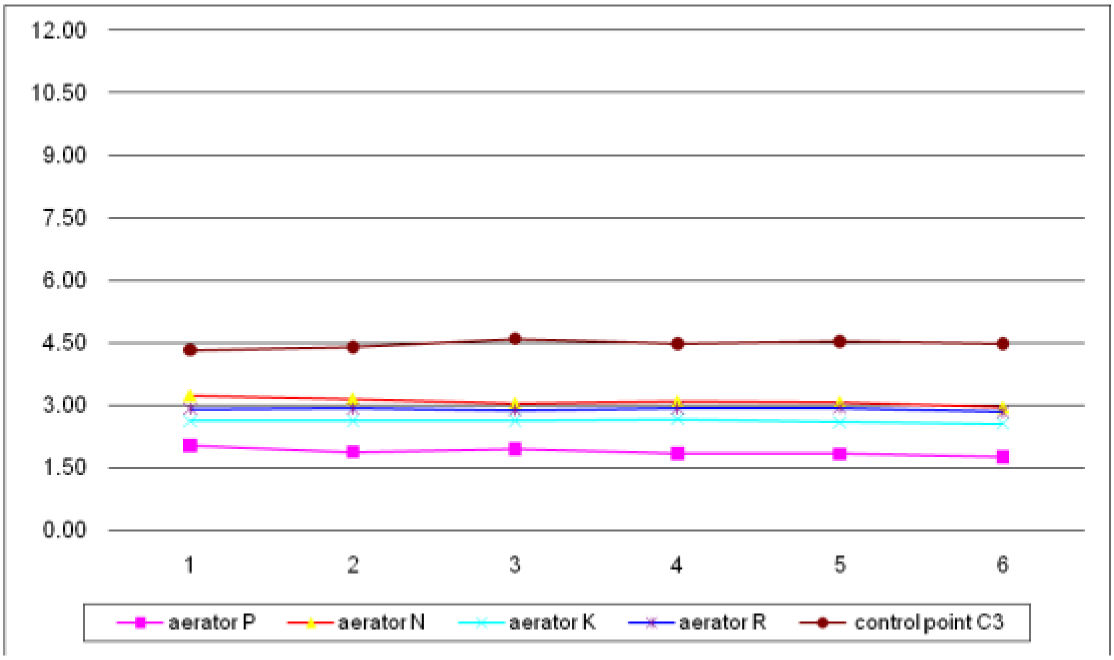

Figure 4.19 Water flow rate of different type of aerators and control point under 1.5 bar water pressure

Table 4.19 displays the percentage of the water flow rate from different aerators relative to control point under 1.5 bar of water pressure. In cycle one The flow rate from aerator type P presented 47.01% in comparison to control point and 74.64 %, 50.47% and 67.22% for aerators N, K and

R respectively. The table shows the variations in flow rate percentages in the next cycles. Figure 4.20 shows the percentage of water flow rate from faucet aerators relative to control point all under 1.5 water bar.

Table 4.19 percentage of water flow rate relative to control point under 1.5 bar water pressure

Cycle no.	% of Aerator P	% of Aerator N	% of Aerator K	% of Aerator R
1	47.01	74.64	60.47	67.22
2	42.73	71.8	59.82	66.42
3	42.32	66.21	57.12	62.59
4	41.09	68.94	59.46	65.36
5	39.3	65.78	57.06	63.33
6	42.13	69.21	58.53	64.97

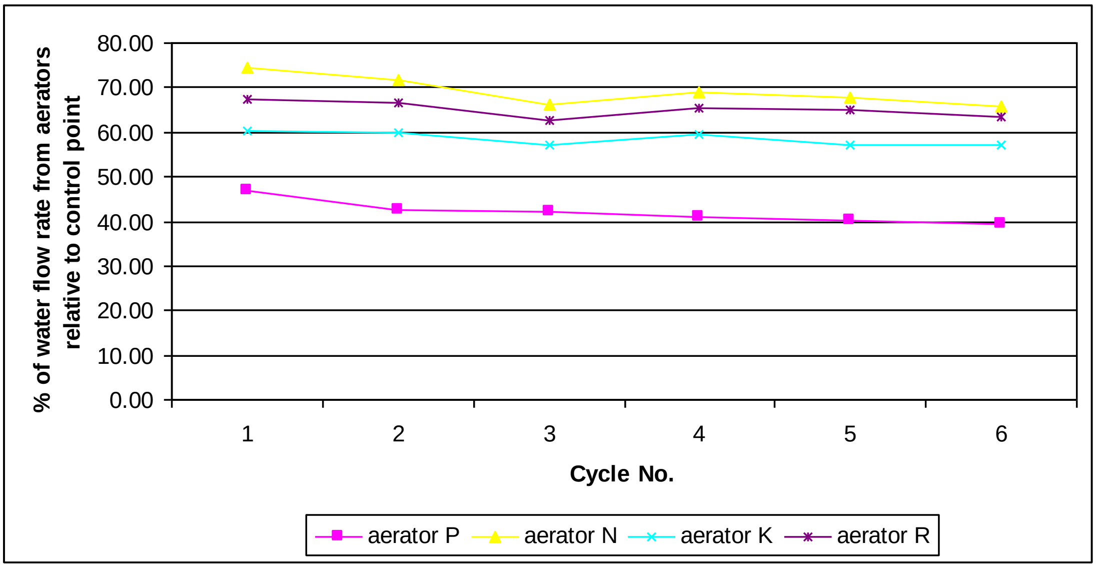

Figure 4.20: The percentage of water flow rate from faucet aerators relative to control point all under 1.5 water bar.

At the end of the study the all aerators were dismantled. It was observed that sediments clogged part of the aerators. (See Figure A.4 in the Appendix A). The sediments seemed to be more in aerators under 1.5 bar and 2 bar. In the next chapter a discussion of the above mentioned results will be demonstrated.

Chapter 5 - Discussion

As shown in Table 4.12, the different values of HPC in the aerators (regardless of their type) and the control points under the same water pressure, reflected that under a 2 bar water pressure, the HPC concentrations exceeded the HPC in the control point (faucet without aerator) during cycles 2, 3, 5 and 6. Furthermore, under 1.5 water bar, the HPC concentrations in the aerators exceeded the HPC in the control point in all cycles except cycle 1. On the other hand, under 2.5 bar water pressure the HPC concentrations in the aerators was less than the HPC in the control point during all cycles except cycle 5. This may lead to the conclusion that high water pressure could increase the flow of the water and inhibit the accumulation of sediments in the aerators, thus enhancing bacterial growth. These results confirmed the outcome reached by Momba (2000) that, sediment promotes bacterial growth in water.

It is worth mentioning that, as shown in Table 4.8 during all cycles except cycles 5 and 6, the HPC concentration in the phase three water tank in Dubai International Academic City (DIAC) exceeded the threshold level of 500 cfu/ml. This threshold is recommended by Dubai Municipality as well as international standards. This indicated that the level of residual disinfectant was insufficient in the water system in cycle 1 to cycle 4. It is also useful to point out that the occurrence of HPC concentration was relatively high in comparison to results from other studies. For example Francisque et al. 2009, Huang and E. 2007 and Delahaye et al. 2003.

The results indicated that, the monitoring of the water quality in the water distribution system may be insufficient as, the HPC level in the tank from cycle 1 to cycle 4 (October-2101 until January-2011) was very high. It appears DEWA does not conduct a regular test for HPC. An interview with DEWA staff revealed that, only total coliform and E.coli tests were conducted on regular basis on the external water supply system. This practice does not fulfill the recommendations made by Reasoner (2004) that, HPC tests should be conducted in parallel with total coliform tests on water distribution samples, because the high HPC content may inhibit the growth of coliform bacteria (Allen et al. 2004).

Furthermore in cycle two HPC concentration dramatically increased in DIAC water tank although the water temperature and pH of the water did not change from cycle one. This indicated that the disinfectant concentration had decreased in the water supply.

In cycle two there was a dramatic increase in the HPC concentration in the water tank as seen in Table 4.8, however there was a decrease in HPC concentration in all types of aerators N, R, K and P as seen in Tables 4.1 to 4.4, this may be due to contamination from the source itself. Since most of the campuses in DIAC were off on Friday and Saturday which means water was stored in the tank for two days prior to collection of the water samples.

By considering the average HPC bacteria concentration in the aerators regardless of the different water pressure, in cycle 5 and 6, as shown in Tables 4-1 to 4-5, it was noted that the lowest average concentration was found in aerator type P. As mentioned in chapter three this type is unbreakable single piece insert which provided non-splashing and non-aerated spray additionally, it is a pressure compensating aerator which may has less effect on bacterial growth.

As presented in Table 4.8, it is interesting to note that the HPC concentration in the water tank at the end of the study was reduced to levels below 500 cfu/ml which met the standard of water quality in Dubai. Moreover, the temperature of the water in DIAC tank phase three was 36 C° in the first cycle on October then, gradually reduced to 31 C° in cycle 6 on March as shown in Table 4.13. The reduction in water temperature was not very significant in comparison to air temperature fluctuation over the seasons. This might be because of the source of the water supply from desalination plants normally produces warm water. The reduction of HPC level over the cycle confirm previous studies that there is a positive correlation between the water temperature and HPC concentration (Carter et al. (2000), Francisque et al. (2009))

Moreover there was significant variations between water temperature in the water tank and water temperature from the faucets as seen in table 4.13, it is worthy mentioning that the air conditioning in the washroom area was the main reason for the lower temperature in the washroom. Furthermore, there was quite a long distance for water to travel between the water tank in phase three and washrooms. In addition, it is useful to mention that all samples and measurements were taken in the early morning except for cycle 1 in which the samples were taken evening time. This is the reason for the high temperature of the water from the aerators in cycle 1.

Previous studies conducted by Francisque et al. (2009) and Carter et al. (2000) concluded that alkalinity of the water enhances the HPC growth. However, as seen in chapter four the result of HPC from water tank samples revealed the opposite, when the pH of the water tank was 7.9 in cycle one the HPC concentration was 19,460 cfu/ml and when the pH increased to 8.9, the HPC dramatically dropped to 230 cfu/ml. I was unable to find the source of the carbonate in the external distribution system which enhanced the increase of the pH result because, there was no data available.

The drop in HPC levels in DIAC water tank after cycle two which was after DEWA recognize that, there had been a breakdown in the vacuum regulator for water chlorination in December 2010. This meant that manual chlorination in Muchrif complex reservoir with calcium hypo-chloride could have reduced the HPC in cycle two from 4600 cfu/ml to 17,500 cfu/ml. However, the HPC concentrations remained high in all faucets. The reason for this could be that, the plumbing material in the DIAC system promoted the re-growth of the bacteria which confirm previous studied by Moritz et al. (2010), that plastic pipes enhancing the formation of the bacteria and biofilm.

The aerator works as obstacle for the sediment and inhibit it to flow with water which could has two effects. The first effect is that, the sediments may contain biodegradable organic matter which setup foundation for the forming of biofilm (Momba 2000). The second effect is deterioration of the efficiency of the aerators by reducing the water flow rate over time; thus regular maintenance and cleaning is required to avoid deterioration.

It was noted that, flow rate from all faucets under 1.5 bar and 2 bar water pressure both with and without aerators, have a flow rate that complies with green building features that maximum flow rate is 6 L/min. Additionally, the water flow rate from aerator type P confirm the manufacturer claim that it has potential to keep a constant water flow regardless of the water pressure as seen in tables 4.14 to 4.18. Additionally it offered higher water saving than the other types with an average saving of 58% to 83% in comparison to the control point. This type was closely followed by type K, R and N. with saving 41% to 65%, 24% to 59% and 21% to 53% respectively. Although there is higher water saving with type P, it may also cause inconvenience to the end user due to slow rate.

Moreover, as seen in Tables 4.14 and 4.18 a decrease in the flow rates from aerators under 1.5 bar and 2 bar were noted over the cycles despite the flow rate in the control points under the same pressure being slightly increased. This was because of an accumulation of sediments in the aerators may have compromised their efficiency.

On the other hand, it was noted that all faucets under 2.5 pressure of water bar excluding the control point (the faucet without aerator) complied with the green building features proposed by DEWA. The flow rate in the control point was above 9 L/min and the flow rate in type P was the least followed by types K, R and N respectively however, a gain the flow rate in Type P might caused inconvenience to the end users. It was obvious that type P saved about 83 % of the water relative to the control point followed by 66% in type K then 65 % in type R and 53% in type N.

Chapter 6 - Conclusion and Recommendations

6.1 Conclusion

In short, water scarcity has forced many regulations to appear to enhance water conservation. One of the green building features is water saving using plumbing fixtures such as faucet aerators. The rationale for the study was to investigate the effect of the water faucet aerators on bacterial growth which could have affected the quality of the water. An experimental method was followed consequently, during the six months, 120 water samples were collected from Dubai International Academic City's (DIAC) plumbing system, mainly from faucet with and without aerators under different water pressure. Also water samples from the tank in phase three were tested. HPC test was performed on the samples in Dubai Municipality Central Laboratory. Additionally, water parameters included pH, Temperature of the water and air temperature in addition to water flow rate were measured in the field.

The results revealed that, the supplied water to DIAC campus was contaminated with HPC bacteria. The concentration of the bacteria exceeded the threshold level of 500 cfu/ml set by Dubai Municipality. In addition to contamination of the water supplied from outside DIAC there were another contributors to enhance the growth of the bacteria inside the water supply system in DIAC such as, P.V.C pipes and the faucet aerators. Although the supplied water was treated after cycle four, which resulted in reducing the HPC concentration in the water tank, the HPC concentration in the internal water supply system remained high because of the above mentioned contributors.

It was noted that the HPC concentration in water from faucet aerators under 1.5 and 2 water bar greater than the HPC concentration in water from faucet control point (Faucet without aerator). This result indicated that the faucet aerators under and less than 2 bar water pressure enhance HPC bacterial growth in the water supply system. As the low water pressure cause accumulation of the sediments on the internal surface of the aerators. This was not the case with faucets under 2.5 water bar, as there was no significant different in the HPC level between the aerators and the control point under 2.5 water bar pressure.

Despite the fact that 2.5 water bar has less impact on the bacterial growth than 2 and 1.5 water bar pressures, the contamination of the HPC occurred in the entire internal water supply system including faucet with or without aerator due to pluming material. This result lead to a conclusion that, regular maintenance for the internal water supply system can avoid such contamination. As understood from with the Facility Management in DIAC that, usually no intervention or treatment by DIAC to the internal water supply system since the water is supplied by DEWA. However; as seen in chapter four that the supplied water itself was contaminated until cycle four.

Furthermore, the current monitoring practice for water quality in external water supply system is insufficient. As they use only E-coli and Total coliform tests. The presence of HPC in high concentration may inhibit the growth of Total coliform and E-coli bacteria which may give a good indication for the water quality however it is not. So it is recommended to perform the total coliform and E-coli tests in parallel with the HPC test.

It is worthy to mention that, I have been informed by DEWA inspector that, they are going to implement such practice in their monitoring.

All aerators have the potential to conserve water, however; the water saving depends on the aerator types and the different water pressure. In this study the saved water was from 20 % to 80 %. The aerator type P was the premium saver. Additionally, it confirmed the manufacturer claimed that aerator type P has a potential to keep constant water flow rate regardless of the water pressure variations, since this type can compensate the water pressure. On the other hand, this type has disadvantage that it may compromise the end users due to its low flow rate.

It is worthy to mention that, the water flow rate from faucets (under water pressure less than 2 water bar) whether they have aerator or not met the green building requirements that the maximum water flow rate is maximum 6 L/ min. Using the aerator under water pressure less than 2 water bar has two impacts;

The 1st impact which is positive as it reduced the water splash and produces a fine stream flow. On the other hand it has disadvantage that, the aerator under water pressure less than 2 bar enhanced the re-growth of bacteria due to accumulation of sediment on the internal surface of the aerator. This disadvantage can be avoided by regular maintenance for the aerators. This period should not exceed three month or, based on the results of HPC tests which is less.

Additionally, the efficiency of faucet aerators in water saving under 2 bar and 1.5 bar were reduced due to accumulation of sediments in the internal surface of the aerators.

Furthermore, the water flow rate from faucets under 2.5 water bar discovered that, using faucets with aerators can save water based on the aerator types. In this research, aerator type P was the premium saver followed by type K, R and N respectively.

In conclusion, it is useful to mention that, although there are benefits from using aerators in reduce the water splash in addition to water and energy saving, aerator use under low water pressure condition has disadvantages that it may enhance bacterial growth. This can be minimized through extensive water monitoring and maintenance of the plumbing fixtures.

6.2 Recommendation

Finally, the following are highly recommended:

It is suggested that periodic water samples be collected from the internal water supply system in DIAC for HPC periodically regardless of the status of water quality supplied by the main source, because the internal plumbing may compromise the water quality. Particularly, when retrofitting fixtures are fixed, since these fixtures have the potential to conserve the water. This means the water will be stored for a longer period of time than expected in original design of the tank. This might result in stagnation of the water which could contribute to the re-growth of bacteria.

It is highly recommended that implementation maintenance and cleaning of the aerators based on the water sample test's results discussed in an aforementioned point. Otherwise execution of three monthly maintenance is recommended to eliminate the growth of bacteria be conducted to eliminate formation of biodegradable organic matter on the internal side of the aerator also to maintain the efficiency water flow via the aerator.

Future studies should consider the followings:

-To increase the number of aerators under study, also the water parameters from the external water supply system will be measured in parallel with measurement from the internal water supply system which could provide a comprehensive information and date about water parameters inside and outside the building.

-The time for water sampling should take into consideration month of July since the temperature in this month at its highest the maximum in U.A.E during this month.

- The washrooms where the aerators will be fixed should not be air conditioned since this factor may affect the result.

-The future study should think about the impact of water saving on the water pipes size and water tank volume, which have cost implication especially in buildings where retrofitting of plumbing fixtures are installed.

- The future studies should study the impact of other plumbing fixtures such as showerhead on the bacterial growth.

References:

Absel, R. (2010). Free Water-Saving Devices for UAE Homes. *Gulf news* [online] 13 January, [Accessed 15 August 2010]. Available at: http://gulfnews.com/news/gulf/uae/environment/free-water-saving-devices-for-uae-homes-1.567149

Abu Dhabi Urban Planning Council (2010). *Estidama* [Online]. [Accessed 7 March 1011]. Available at: http://estidama.org/

Al-Mazroui, H. & AL-Mansouri, M. (2010). International Conference on Agrarian Reform and Rural Development [online]. [Accessed 15 February 2011]. Available at:

http://www.google.ae/search?q=Al-Mazroui+%26+AL-Mansouri.+International+Conference+on+Agrarian+Reform+and+Rural+Development&sourceid=navclient&ie=UTF-8&rlz=1T4ADFA_enAE375AE378&aq=f&aqi=&aql=&oq

Allen, M., Edberg, C. & Reasoner, D. (2004). Heterotrophic Plate Count Bacteria-What is their Significance in Drinking Water?. *International Journal of Food Microbiology* [Online]. Vol.92.PP. 265-274. [Accessed 20 October 2010]. Available at: http://www.sciencedirect.com/

Anderson. J., Sud. S. & Paper. T. (2002). My Data 360 [online]. [Accessed 9 January 2011]. Available at: www.data360.org

Bartram, J., Contruvo, J., Exner, M., Fricker, C. & Glasmacher, A. (2003). *Heterotrophic Plate Counts and Drinking Water Safety* .London: IWA publishing.

Binggeli, C. (2010). *Building Systems for Interior Designers*. 2nd ed. New Jersey: John Wiley & Sons.

Bokaders, V. & Block, M. (2010). *The whole Building Hand Book*. Sterling: Earthscan.

Carter, T. Rice, E., Buchberger, S. & Lee, Y. (2000). Relationship between levels of Heterotrophic Bacteria and Water Quality parameter in drinking water distribution systems. *Water Research*. [Online]. vol 34(5)PP.1495-1502. [Accessed 23 October 2010]. Available at: http://www.sciencedirect.com/

Central Intelligence Agency (CIA) (2010). *The World Fact bo*ok [online].U.S.A. [Accessed 20 August 2010]. Available at: https://www.cia.gov/library/publications/the-world-factbook/geos/ae.html

Ciesielski, C., Blaser, M. & Wang, W. (1984). Role of Stagnation and Obstruction of Water Flow in Isolation of Legionella Pneumophila from Hospital Plumbing. *Applied and Environmental Microbiology* [Online]. vol. 84 (5) PP.984-987[Accessed 5 September 2010]. Available at: http://aem.asm.org/cgi/content/abstract/48/5/984

Dawoud, M. (2005). The Role of Desalination in Augmentation of water supply in GCC Countries. *Desalination* [online].vol.186 ,p.p 187-198. [Accessed 7 October 2010]. Available at: http://www.sciencedirect.com

Demriz, M. (2006). *Application of Dry Urinals* [online]. Germany: Gelsenkirchen University of Applied Sciences. [Accessed 24 August 2010]. available at: http://www.allianceforwaterefficiency.org/resource-library/default.aspx

Dubai Electricity and Water Authority (2009). *Water Statistics* [online]. Dubai: [Accessed17August2010].Available at: http://www.dewa.gov.ae/aboutus/waterStats2009.aspx

Dubai Statistical Center (2009). *Statistical Yearbook-Emirates of Dubai*

Dubai Electricity and Water Authority (2010). *Green Building Regulation* [online].[Accessed25August 2010].Available at: http://www.dewa.gov.ae/images/gb/greenbuilding2010e.pdf

Elie, A. (1992).*Concealed Liquid Flow Aerator* [online]. [Acceded 4 March 2011]. Available at: http://www.wipo.int/pctdb/en/wo.jsp?WO=1983001266&IA=US1981001341&DISPLAY=STATUS

Environment Agency Abu-Dhabi (2011).Water-savers Campaign [online]. [Accessed 27 February 2011]. Available at: http://www.watersavers.ae/en/watersavers.php?p=3

EPA (2010).Water Sense [online]. [Accessed 10 January 2011] Available at: http://www.epa.gov/WaterSense/products/showerheads.html

Ford, T. (1999). Microbiological Safety Of Drinking Water: *United States and Global Perspectives* [online].107(1) PP.171-206 .[Accessed 5 September 2010]. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1566363/

Foster, K. Stelmack, A. and Hindman, D. (2007). *Sustainable Residential Design*. New Jersey: John Wiley & Sons.

Friedler, E. Kovalio, R. & Galil, N. (2005). On Site Grey-water treatment and Reuse in Multi-story Buildings. *Water Science Technology*. [online].vol.51(10) pp.187-194.[Accessed 22 August 2010].available at:
http://gwri-ic.technion.ac.il/pdf/Professors/Noah_Galil/3.pdf

Francisque, A., Rodriguez, M., Moreno, L. , Sadiq. R. & Proulx, F. (2009). Modeling of Heterotrophic Bacteria Counts in a Water Distribution System. *Water Research* [on line] vol.(43)PP. 1075-1087. [Accessed on 25 October 2010]. Available at
http://www.sciencedirect.com

Garrett, R. (2000). *Hot and Cold Water Supply*. 2nd ed. Oxford: Blackwell.

Gleick, P. (1999). The Human Right to Water. *Water Policy* [On line] vol.(1)PP. 487-503.[Accessed on 5 March 2011]. Available at
http://webworld.unesco.org/Water/wwap/pccp/cd/pdf/educational_tools/course_modules/reference_documents/issues/thehumanrighttowater.pdf

Global Footprint Network (2010). *Ecological Footprint and Biocapacity* [online]. [Accessed on 15 March 2011]. Available at:
http://www.footprintnetwork.org/images/uploads/2010_NFA_data_tables.xls

Gray, N. (2008). *Drinking Water Quality Problems and Solutions*. 2nd ed. Cambridge: Cambridge University Press.

Harvey, L. (2006). *A Handbook on Low-Energy Buildings and District-Energy Systems*.1 st ed. London: Danny Harvey.

Heroes of the U.A.E (2011). *Water-savers* [Online]. [accessed 6 February 2011]. Available at: http://water.heroesoftheuae.ae/en/conservation/water-conservation/how-does-it-work.html

Huang, W. and Lin, Y. (2007).A controlled Study of Legionella concentration in Water from Faucets with Aerators or Laminar Water Flow Devices. *Infection Control and Hospital Epidemiology* [online]. vol.28(6) pp 765-766. [Accessed 1 October 2010]. Available at http://www.specialpathogenslab.com/SPL-Advantage/Huang%20and%20Lin%20ICHE%202007-Aerators-Laminar-Flow-Infection-Control.pdf

Hargreaves, J., Shireley, L. Bren., V. Fillipi, G., Lacher, C., Esslinger, V. and Watne, T. (2001). Bacterial Contamination Associated with Electronic Faucets. A new Risk for Healthcare Facilities. *Infection Control and Hospital Epidemiology* [Online]. vol.22 (4) pp 202-205. [Accessed 5 November 2010]. Available at: http://www.sciencedirect.com

H2O (2010). 'DESAL COSTS. UAE spends Dh 11.8 billion on desalination', September, p. 6.

Ideal Standard (2005). *Water Saving Ideal* [online]. Kingston Upon Hull: [Accessed 31 July 2010]. Available at: http://www.thebluebook.co.uk/pdfs/brochures/Mixed-Watersaving06.pdf

Jones, L. (2008). *Environmentally Responsible Design*. 1st ed. New Jersey: John Wiley & Sons.

Juror, J. (1946). Life Magazine. *Waterfall Faucet* [Online]. [Accessed 5 March 2011]. Available at:
http://books.google.ae/books

Kakande, Y. (2008). Desalination plant forced to close by red tide may reopen. The National.[online] 6 November .[Accessed 26 February 2011]. Available at:
http://www.thenational.ae/news/uae-news/desalination-plant-forced-to-close-by-red-tide-may-reopen

Kappstein, I., Grundmann, H., Hauer, T., & Niemeyer, C. (2000). Aerators as Reservoir of Acinetobacter Junii , An Outbreak of Bacteraemia in Paediatric Ancology Patinas. *Journal of Hospital Infection* [online] vol. 44 pp. 27-30 [Accessed 10 June 2010]. Available at: http://www.sciencedirect.com/

Lattemann, S. & Hopner, T. (2008) Environmental Impact and Impact Assessment of Seawater Desalination. *Desalination* [Online]. vol. 220 pp.1-15. [Accessed 20 August 2010]. Available at:
http://www.desline.com/articoli/8958.pdf

Lehtola, M. Laxander, M. Miettinen, I. Hirvonen, A. Vartiainen, T. & Martikainen, P. (2006). The effect of changing Water Flow Velocity on the formation of biofilms and Water Quality in Pilot Distribution System Consisting of Copper or Polyethylene Pipes. *Water Research* [.online]. vol. 40. PP 2151-2160. [Accessed 5 September 2010].Available at:
http://www.sciencedirect.com

LEED (2009). *Reference Guide for Green Building Design and Construction*. Washington: Green Building Council.

Mihelcic, J. & Zimmerman, J. (2010). *Environmental Engineering: Fundamentals, Sustainability, Design*. Hoboken: John Wiley & Sons.

Moritz, M. Flemming, H. & Wingender, J. (2010). Integration of pseudomonas aeruginosa and Legionella pneumophila in drinking water biofilms grown on domestic plumbing materials. *International Journal of Hygiene and Environmental Health* [online]. vol.213pp.190-197. [Accessed 12 September 2010]. Available at: http://www.sciencedirect.com/science

Moughtin, C. & Shirley. P. (2005). *Urban Design: Green Dimension. Amsterdam*: Elsevier.

NAHB Research Center (2001). *Low Flow Plumbing Fixtures*: [Online].Maryland. [Accessed 31 July 2010].Available at: http://www.toolbase.org/Building-Systems/Plumbing/low-flow-plumbing-fixtures

(Neoperl 2010). [online]. [Accessed 15 September 2010].available at http://www.neoperl.net/en/oem/products/aerators/pressurecompensating.html

Nguyen, C., Edwards, M., DiGiano, F., Elfland, C. & Tech, V. (2008). *Resolving Water Quality Issues in Premise Plumbing Systems with Advance Water Conservations Features*. University of North Carolina at Chapel Hill [On line]. [Accessed 3 November 2010]. Available at:www.nzsses.auckland.ac.nz/.../2008/.../Nguyen-Edwards-DiGiano-Elfland.pdf

Orenstein, P. Consolacion, N. Amihod, B. Perna, S. & Miller, M.(2006). Infection Control and Plumber: Neonatal ICU Outbreak OF Pseudomonas and Stenotrophomonas Traced to Contamination Water Tap Aerator. *Infection Prevention and Control* [online]. vol.34(5) PP73-74.[Accessed 1 Oct. 2010]. Available at:
http://www.ajicjournal.org/article/S0196-6553(06)00663-8/abstract

Plumber surplus (2010). *Bathroom Faucets*.[online].California:[Accessed 23 August 2010]. Available at:
http://www.plumbersurplus.com/Cat/Bathroom-Faucets/99

Prestomat2000 (2011). *Self closing taps* [online]. [accessed 9 February 2011]. Available at :
http://www.archiexpo.com/prod/presto/commercial-washbasin-self-closing-taps-211-176263.html

Reasoner, D. (2004).Heterotrophic Plate Count Methodology in the United States. *International journal of Food Microbiology* [on line]. vol.(92) PP.307-315.[Accessed 22 October 2010]. Available at:
http://www.sciencedirect.com/

Rogers, J. Dowsett, A. Deennis, P. Lee, J. & Keevil, C. (1994). Influence of Temperature and Plumbing Material Selection on Biofilm Formation and Growth of Legionella Pneumophila in Model Water System Containing Complex Microbial Flora. *Applied And Environmental Microbiology* [online]. vol.6(5) pp.1585-1592.[Accessed 2 September 2010]. Available at:
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC201521/pdf/aem00022-0203.pdf

Roaf, S., Fuenes, M. &Thomas, S. (2007). *Ecohouse*. Oxford: Elsevier.

RST ,Water saving system (2010). [On line]. [Accessed 6 Oct. 2010] Available at: http://www.rst.co.za/index.php?option=com_content&view=article&id=47&Itemid=54

Shane, W. (2008). *Persistence of Spore Forming Bacteria On Drinking Water Biofilm and evaluation of Decontamination Method*. M,sc. Thesis. University of Cincinnat.[Accessed 7 September 2010]. Available at: http://etd.ohiolink.edu/send-pdf.cgi/SHANE%20WILLIAM.pdf?ucin1205164893

Stein, B. Reynolds, J. Grondzik, W. and Kwok, A. (2006).*Mechanical and Electrical Equipment for Buildings.*10 th ed. New Jersey: John Wiley & Sons.

Strelkauskas, A. Strelkauskas, J. Strelkauskas, D. (2010). *Microbiology a Clinical Approach*. New York: Garland Science.

Sustainable Building Design manual.(2004). Delhi: Multiplex [On line]. [Accessed 25 February 2011]. Available at : http://books.google.ae/books

Thompson, J and Sorvig, K. (2008). *Sustainable Landscape Construction*.2nd ed. Washington: Island Press.

UNESCO (2010). *World Water Assessment Program*.[on line]. [Accessed 10 January 2011]. Available at: http://www.unesco.org/water/

waiTEK (2009) Shower Monitor.[online]. [Accessed 8 February 2011]. Available at:http://www.waitek.co.nz/testimonials.html

Wang, J., Chen, M., Lin, Y., Chang, Sh., & Chen, Y. (2009). Association between Contaminated Faucets and Colonization or Infection by Nonfermenting Gram-Negative Bacteria in Intensive Care Units in Taiwan. *Journal Of Clinical Microbiology* [Online]. vol.47(10) PP 3226-3230.[Accessed 25 December 2101]. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2756896/

Walker, w., (2005) *The Strength and Weaknesses of Research Designa Involving Quantitative Measures*. Journal of Research in Nursing. [online] 10 pp. 571-582 [Accessed 20 June 2010]. Available at http://www.sciencedirect.com/

Weber, D. Rutala, W. Blan, Chet, Ch. Jordan, M . and Gergen, M. (1999). Faucets Aerators: A source of Patients colonization with Stenotrophomonas Maltophilia. *AJIC AM J Infect Control* [online].vol.pp59-63 . [Accessed 25 June 2010]. Available at http://www.ncbi.nlm.nih.gov/pubmed/9949380

William, J. and Sorvig, K. (2008).*Sustainable Landscape construction*. Washington: Island press.

Willis, R. Stewart, R. Panuwatwanich, K. Jones, S. and Kyriades, A.(2010).Alarming Visual Display Monitors affecting shower and Use Water and Energy Conservation in Australian Residential Household. Resources. *Conservation and recycling* [online]. vol.54(12) pp.1117-1127 .[Accessed 20 August 2010]. Available at : http://www.sciencedirect.com/

World Health Organization (2003). *Domestic Water Quantity Services Level and Health*. Switzerland: World Health Organization.

Wright, R. & Boorse, D. (2011). *Environmental Science Toward A Sustainable Future*. San Francisco: Pearson.

Appendix A

Photos of DIAC plumbing material in DIAC washroom

Figure A.1 water supply material

Figure A.2 Plumbing Materials in DIAC water supply system

Figure A.3 Washroom in DIAC

Figure A.4 Sediments accumulation on the faucet aerator

Appendix B

Sample of Dubai Municipality laboratory test report