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GIS-based Non-Revenue Water Mapping and Analysis

By

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Abstract

Water loss from water distribution network is a major concern to water utilities. Water utilities around the world are becoming more focused on adopting a proactive approach to managing water loss. The amount of lost water can be significant, reaching levels as high as 50% of production. Abu Dhabi Distribution Company, the main distributor of potable water in the Emirate of Abu Dhabi, is widely paying attention to water losses and investing in their resources to reduce it to the acceptable level as per Abu Dhabi Emirate Regulation Entity. Water balance analysis is the most widely used method for quantifying water losses. Guidelines and standard procedures for performing water balance analysis is mainly provided as a best practice document by the International Water Association (IWA). Experience shows that successful implementation of this best practice depends to a large extent on the ability to efficiently collect and integrate data from various sources. These data sources include metered and un-metered consumption records, water supply data, and water network asset inventory. It will also require an understanding of various components contributing to the water loss.

This paper illustrates the developing of a GIS-based method to facilitate identification of non-revenue water as part of water balance analysis procedure. The analysis integrates data from GIS asset, water interface points' record, Sector Measuring points data loggers' system and Consumption records. The paper also compares the non-revenue water percentage in different years for selected sectors and highlights the areas with high percentage comparing with others and against the international average non-revenue water percentage. The analysis was conducted for Abu Dhabi Island.

Literature Review

Continuous calculation of water balance together with the night flow measurements on regular basis considered as the best practice in management of water losses. The water balance, usually taken over a 12-months period and should include (IWA, 2000):

- A comprehensive accounting of all water into and out of a distribution system, including inspection of system records;
- An ongoing meter testing and calibration program
- Due allowance for the time lags between production meter reading and customer meter reading.

The water balance calculation consists of quantifying volumes of total water entering the system, authorized consumption - billed and unbilled, metered and unmetered and water apparent and real losses, see figure 1. In the absence of continuous leak detection, the process could also involve a benefit cost analysis to recover excess leakage, which leads to a leak detection program. All water balance calculations are estimated to some degree because of the difficulty of evaluating all the components with complete accurateness. The reliability is considered to be greatest when input volumes are purchased. Storage tanks can result in low flow rates through service connections, and these low flows may not register accurately on the customer meter. As recommended by the IWA Performance Indicators Group, the best practice is to allocate confidence grades to all components of the water balance that incorporate both reliability and accuracy grading (IWA, 2000).

Every component of the annual water balance figure 1 should always be presented in terms of volume per year. The steps shown under Figure 1 are used to calculate the annual volumes of Non-Revenue Water, Water Losses, Apparent Losses and Real Losses. With regard to Step 9 of the calculation process recommends that Real Losses volume calculated by the difference between Water Losses and Apparent Background losses from very small undetectable leaks - typically low flow rates, long duration, large volumes (IWA 2000);

- Losses from leaks and bursts reported to the water provider - typically high flow rates, short duration, moderate volumes;
- Losses from unreported bursts, found by active leakage control (ALC) - medium flow rates, but duration and volume depends on ALC policy;
- Service reservoirs Overflows and leakage.

Methods of assessing Real Losses, other than from Water Balances, include (IWA 2000):

- Analyzing night flows based on district meter data
- Recording numbers and types of leaks and bursts and their average flow rates and durations
- Modelling calculations which allow for background leakage and pressure.

For demand management purposes (IWA 2000), considering the physical losses after the point of customer metering is highly significant and worthy of attention.

<table>
<tr><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th></tr>
<tr><td rowspan="7">System Input Volume

M^3/year</td><td rowspan="3">Authorised Consumption

M^3/year</td><td rowspan="2">Billed Authorised Consumption

M^3/year</td><td>Billed Metered Consumption (including water exported)</td><td rowspan="2">Revenue Water

M^3/year</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption

M^3/year</td><td>Billed Unmetered Consumption</td><td rowspan="5">Non-Revenue Water

M^3/year</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="4">Water Losses

M^3/year</td><td rowspan="2">Apparent Losses

M^3/year</td><td>Unauthorised Consumption</td></tr>
<tr><td>Metering Inaccuracies</td></tr>
<tr><td rowspan="3">Real Losses

M^3/year</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer metering</td></tr>
</table>

Figure 1: Components of Water Balance for a Transmission System or a Distribution System

Steps for Calculating Non-Revenue Water

Step 1: Define System Input Volume and enter in Col. A

Step 2: Define Billed Metered Consumption and Billed Unmetered Consumption in Col. D; enter total in Billed Authorized Consumption (Col. C) and Revenue Water (Col. E)

Step 3: Calculate the volume of Non-Revenue Water (Col. E) as System Input Volume (Col. A) minus Revenue Water (Col. E)

Step 4: Define Unbilled Metered Consumption and Unbilled Unmetered Consumption in Col. D; transfer total to Unbilled Authorized Consumption in Col. C

Step 5: Add volumes of Billed Authorized Consumption and Unbilled Authorized Consumption in Col. C; enter sum as Authorized Consumption (top of Col.B)

Step 6: Calculate Water Losses (Col. B) as the difference between System Input Volume (Col.A) and Authorized Consumption (Col. B)

Step 7: Assess components of Unauthorized Consumption and Metering Inaccuracies (Col. D) by best means available, add these and enter sum in Apparent Losses (Col. C)

Step 8: Calculate Real Losses (Col. C) as Water Losses (Col. B) minus Apparent Losses (Col. C)

Step 9: Assess components of real losses (Col. D) by best means available (night flow analysis, burst frequency/flow rate/duration calculations, modelling … etc.), add these and cross-check with volume of Real Losses in Col. C which was derived from Step 8

Introduction

Water utilities considered the water loss from water distribution as a major concern due to several reasons, such as: loss of scarce water resources and pumping energy, financial loss, and raised health risks due to escalating breakage rates and the possibility of contaminants' intrusion. Water distribution networks deteriorate naturally with time, and subsequently lose their initial water tightness. The main reasons for Water lost is leakage in multiple components of the network: transmission and distribution pipes, service connections, joints, valves, fire hydrants, and storage tanks and reservoirs. Moreover, there is an apparent loss which is non-physical losses, caused by customer meter under-registration, accounting errors, or unauthorized water use.

Water Balancing and Assessment of Non-Revenue Water (NRW) on yearly basis is an essential activity with respect to the performance, revenue generation and social responsibility of the Company. Water Balancing gives an indication of the water being consumed against distributed water, which support the analysis to check the feasibility to reduce unauthorized uses and water lost, which in turn will increase the revenue of the Company. Moreover, water balance analysis will help in controlling and monitoring operational and other types of losses, which successfully increase the capacity of the network. Accordingly, increasing the capacity shall lead to deferral of the capital investment of a new distribution network. Finally, saving the water is a critical social responsibility which promote Abu Dhabi vision of efficient use of resources and contributing to a better quality of life for all.

Currently, Abu Dhabi Distribution Company conducting the IWA water balance analysis manually by collecting the required data from concerned business unit within the company. In this study, the GIS shall be utilized to map, visualize, and analyze the non-revenue water per Abu Dhabi Island sectors by performing two level comparison. The difference between the total Supply volume and Monitored flow of all sectors sector and the difference between Monitored flow and consumption data for each sector. The same shall be in cubic meter per year in order to find the annual percentage of Non-revenue water per sector.

About Abu Dhabi Distribution Company

Abu Dhabi Distribution Company (ADDC) plans, operates, maintains and owns network distribution assets and directly interfaces with water and electricity customers in Abu Dhabi's Central, Eastern and Al Dhafra Regions, leveraging technical expertise and best-practice customer-care solutions.

Through innovation and continuous enhancements, ADDC ensures water and electricity flow to more than 600,000 service points through a smart, robust, efficient and sustainable distribution network.

ADDC is a subsidiary of Abu Dhabi National Energy Company (TAQA).

ADDC is receiving water from Abu Dhabi Transmission Company TRANSCO through a number of interface points. Apart from TRANSCO, ADDC is receiving water from AMPC (RASCO) and distributing among the customers in Delma Island.

Study Area

The study area is Abu Dhabi Island which is part of Abu Dhabi region, the largest and most modern cities in the Middle East and the capital city of the United Arab Emirates. The latitude of Abu Dhabi, United Arab Emirates is 24.466667, and the longitude is 54.366669. The city of Abu Dhabi is on the southeastern side of the Arabian Peninsula. It is on an island less than 250 meters from the mainland. As per the Abu Dhabi Distribution Company GIS data and Consumption records, Abu Dhabi Island consists of 157 sectors and around 190,000 service connection.

GIS benefit for Water Asset Management

According to the Water Infrastructure Network (WIN), reported in 2001 that the utilization of innovations in technology and management by utility companies has reduce operations and maintenance costs by 15% to 40% (Alexander J. S. 2012). In which one of these innovative technologies is GIS which support to analyze and communicate geographic or spatial information associated with physical assets. In 2002, according to the AWWA, 90% of water utilities were at least partially using GIS to assist in applications (Alexander J. S. 2012). Application is an applied use of technology which bonds the gap between pure science and applied usage. Some estimates show that more than 80% of information used by water utilities is georeferenced promoting GIS technology exclusively applicable as a management tool (Alexander J. S. 2012). Spatial location is typically a major common aspect of all the data at a water utility. GIS could serve as a platform in integrating other database systems such as AMI system, SCADA, Hydraulic model, CMMS, … etc. which enable efficient management of data associated with assets and essential for a precise decision making.

Methodology

Effective management of water losses has four main activities: identifying the annual water loss amount, continues asset monitoring and surveying for leakage, developing an economic leakage level, and locating and repairing leaks. Investing in these four areas is successfully improved the capabilities to monitor, manage, and reduce water loss. An example of these developments include uses of standardized Water Balance analysis.

GIS integrates data from ADDC GIS data, water supply interface points records, Consumption data records, and Sector measuring points data loggers' record to visualize and analysis non-revenue water.

Abu Dhabi Island is divided into 157 districts that have well defined boundaries and monitored.

The water consumption data at sectors level and interface points data obtained from Customer Service Directorate at Abu Dhabi Distribution Company for the year 2019 and 2020. The sector measuring points data obtained from Data Loggers system managed by metering unit at Abu Dhabi Distribution Company for the year 2019 and 2020. The GIS data used includes the Abu Dhabi Island sectors, Sector measuring points locations, interface points locations, and water connection points location. The GIS data obtained from Asset Performance and Information Division at Abu Dhabi Distribution Company. Figure 2 below illustrates types of data collected and used in conducting the analysis.

ArcGIS Pro were used to carry out the spatial analysis and graphs and maps generation and MS Excel for data cleansing, filtration and mapping. The total Sector measuring points measured data and consumption data were integrated with the sector layer in order to reflect sectors' relevant data. Interface points data integrated with Interface points layer to reflect the total input volume entering the network from every interface points.

The water connection points layer was merged with Sector layers in order to statistically check the relationship between number of connections and consumption and monitored data and accordingly the percentage of non-revenue water.

The percentage of non-revenue water were calculated for every sectors and visualized accordingly.

Based on above, the selection tools were used to create a layer for the sectors with non-revenue water greater than 12% which is a trigger indicated by the regulatory entity as a maximum allowable water losses percentage. The same tool also used to create a layer for the sectors below or equal to 12% NRW.

Moreover, some sectors were selected to conduct a comparison between the 2019 and 2020 NRW. These sectors are E13, E14, W18_03, W20, W32, and W64.

Statistical analysis tool in ArcGIS Pro were used to sum the consumption data, monitored data, and interface points data that were used to further conduct the comparison and relationship between them.

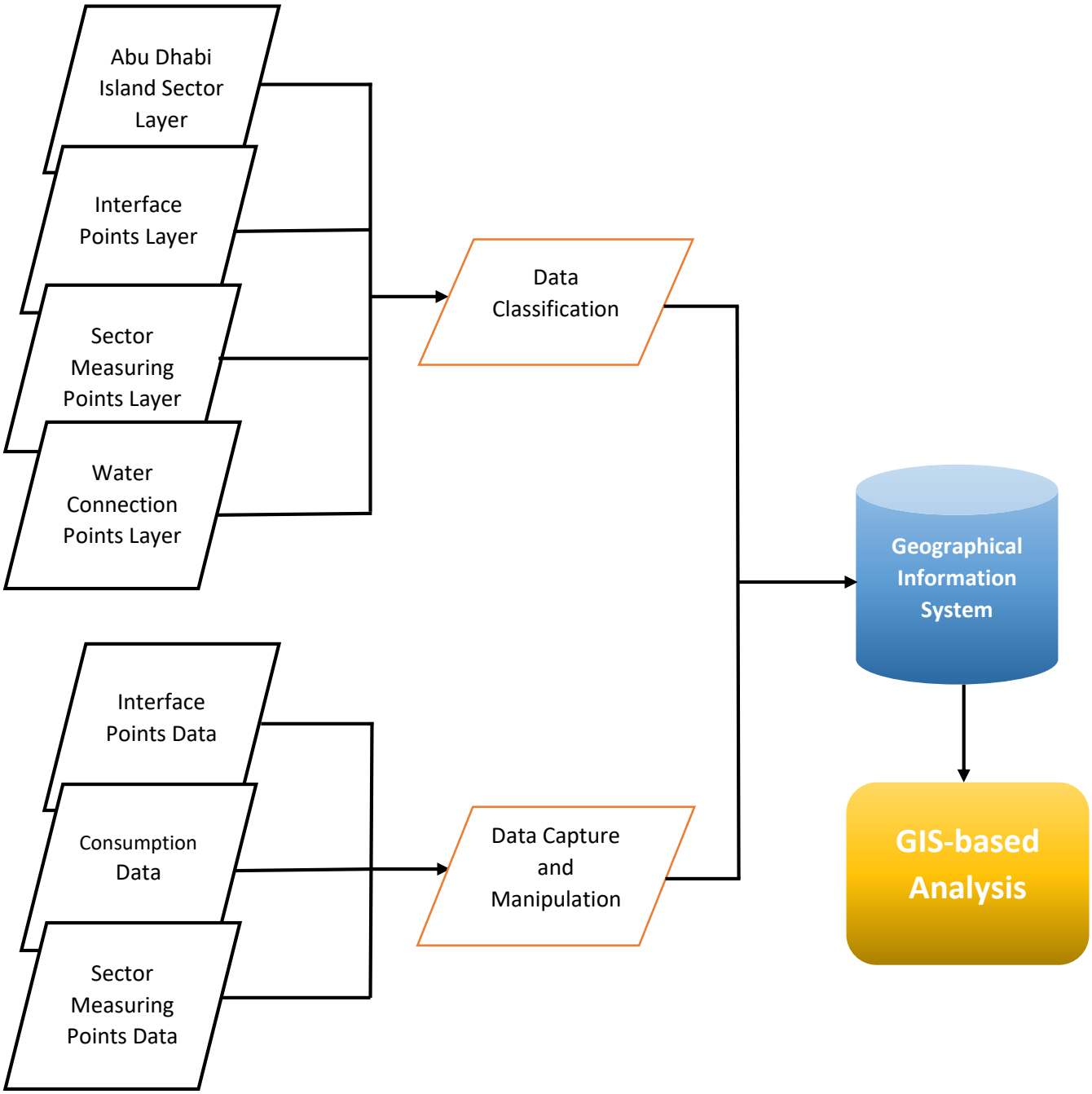

Figure 2: Conceptual Framework

Results & Analysis

Mapping and visualization

Abu Dhabi Island Sectors

This section presents the results of mapping and visualizing the non-revenue water per Abu Dhabi Island Sectors. As mentioned above, currently Abu Dhabi Distribution Company perform the water balance analysis manually comparing the system input volume with consumption data only in which the Non-revenue water per sector is never identified. The same would make it impossible to deal with each sector individually and find the most feasible factors affecting the non-revenue water.

The figure no. 3 below shows the sectors of Abu Dhabi Island considering that these sectors have well defined boundaries and the inflow is monitored. Where the sectors are receiving a flow from one defined meter or sector point are merged together using the edit tool in the ArcGIS Pro. The table no. 1 below indicated the attribute table of the sectors layer after integrating the consumption data, monitored flow, connection points, so that it is spatially distributed and associated with the relevant sector.

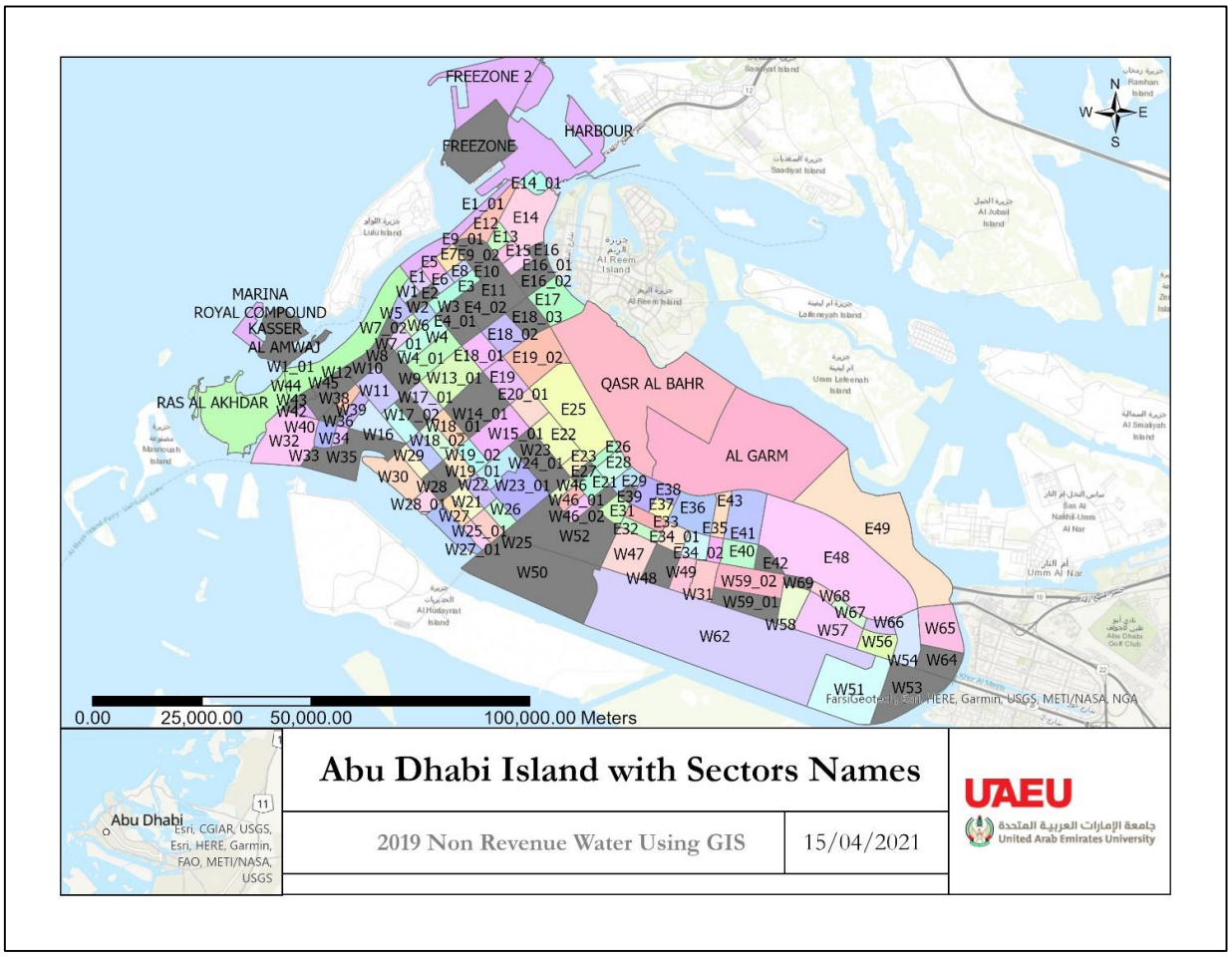

Figure 3: Abu Dhabi Island Sectors

Table 1: Data associated with every Sector

NAME	Service Point	Consumption M3/Y	Monitored M3/Y	NRW M3/Y	Connection Point	2019 NRW Percentage
W27	40	169735	0	-169735	31	-200%
E31	588	308764	887262	578498	217	97%
W65	6	424826	9667	-415159	3	-191%
W18_02	1340	435413	1285917	850504	282	99%
E41	1517	1181168	2218843	1037675	477	61%
W46	122	258439	-146	-258585	90	-200%
W56	175	134201	194251	60050	68	37%
E25	4788	1859962	2013878	153916	126	8%
E12	1797	1613332	1825848	212516	136	12%
E18_01	5445	1960759	-2686299	-4647058	394	1281%
W19_01	125	427818	0	-427818	112	-200%
E1_01	0	0	0	0	19	0%
W33	54	100808	0	-100808	70	-200%
W17_03	563	344085	489022	144937	108	35%
W54	19	1247971	0	-1247971	3	-200%
W68	56	175501	0	-175501	1	-200%
W46_01	264	275037	-8043	-283080	155	-212%
W34	6	403766	-110375	-514141	7	-350%
E16	6407	3088568	2054839	-1033729	172	-40%
E36	405	1041855	1268173	226318	220	20%
E5	2390	531925	814963	283038	88	42%
W58	150	798028	0	-798028	30	-200%
E19_02	3836	2751658	1873610	-878048	691	-38%
E19	2631	1514377	1934864	420487	156	24%
E29	685	243254	555334	312080	81	78%
E23	257	80587	112161	31574	10	33%
W28_01	2	379650	0	-379650	2	-200%
W62	202	4767509	3345418	-1422091	168	-35%
W46_02	164	244444	1438417	1193973	136	142%
E1	2342	1166042	937049	-228993	65	-22%
E26	179	174796	398945	224149	139	78%
E33	1293	428776	10	-428766	280	-200%
E7	1739	418271	487827	69556	82	15%
W24_01	417	671405	1014706	343301	94	41%
E17	11	1530717	204622	-1326095	1	-153%
W23	8	756929	1649303	892374	21	74%
W25	107	282110	361169	79059	68	25%
W18_03	198	209579	3793	-205786	213	-193%
W1_01	9	49518	0	-49518	15	-200%
E18_02	4129	1754115	1812062	57947	324	3%
W42	11	4826471	0	-4826471	15	-200%

E38	365	759512	1367761	608249	210	57%
W16	286	425275	1223922	798647	250	97%
E20_01	3288	1039232	16427	-1022805	236	-194%
E40	3245	821199	455553	-365646	88	-57%
E32	279	383071	530570	147499	28	32%
E8	2234	676445	707286	30841	69	4%
E13	5808	1634230	1628701	-5529	188	0%
W25_01	55	128823	137436	8613	39	6%
W17_01	298	256208	-28729	-284937	216	-251%
E14_01	51	9097	164614	155517	58	179%
W31	289	497831	0	-497831	229	-200%
W1	1102	418037	279008	-139029	43	-40%
W22	271	358293	493343	135050	126	32%
W21	245	332636	45073	-287563	196	-152%
W47	814	1148004	9001	-1139003	595	-197%
W29	50	198754	245539	46785	43	21%
E48	4778	2877399	2674672	-202727	830	-7%
E15	3594	1413992	1312372	-101620	101	-7%
HARBOUR	75	0	0	0	43	0%
W23_01	14	1422351	134249	-1288102	27	-166%
W5	1884	511450	5579452	5068002	50	166%
E6	4290	1084332	704586	-379746	112	-42%
W39	163	279798	0	-279798	127	-200%
W4_01	5	350290	0	-350290	4	-200%
W7_01	1244	385175	973374	588199	149	87%
E34_01	6	87126	59551	-27575	26	-38%
AL GARM	75	308887	0	-308887	68	-200%
MARINA ROYAL COMPOUND	155	0	0	0	103	0%
W51	255	780744	-72	-780816	60	-200%
E37	578	415716	905601	489885	169	74%
W67	12	113747	0	-113747	7	-200%
W19_02	6	772806	0	-772806	26	-200%
W49	204	312115	0	-312115	61	-200%
W11	440	444947	169580469	169135522	329	199%
E22	597	751434	1164732	413298	59	43%
E49	25	1446996	49642	-1397354	12	-187%
RAS AL AKHDAR	13	1771659	0	-1771659	28	-200%
W30	63	2874315	2760600	-113715	109	-4%
E14	4458	1176199	1176199	0	160	0%
W18_01	1434	511594	-11426555	-11938149	340	219%
E34_02	16	142293	275957	133664	64	64%
W13_01	1330	1942329	2176308	233979	43	11%
W37	176	152986	-24641645	-24794631	109	202%
QASR AL BAHR	5	51062	0	-51062	45	-200%

W57	983	472049	727064	255015	12	43%
E21	915	348266	647405	299139	307	60%
E28	775	231882	194704	-37178	70	-17%
W26	4	360975	0	-360975	7	-200%
W6	2203	480538	567123	86585	89	17%
W59_02	98	718348	1156364	438016	105	47%
W66	114	159588	-75986631	-76146219	83	201%
W32	1464	1041802	300764	-741038	26	-110%
W15_01	319	1228105	1795191	567086	205	38%
W3	2	81135	0	-81135	4	-200%
E3	8570	2619638	3116615	496977	232	17%
W64	0	139117	467821	328704	7	108%
W40	0	0	0	0	7	0%
E43	255	324234	430278	106044	190	28%
W4	9186	2160235	2920287	760052	246	30%
W27_01	16	809500	-180443	-989943	12	-315%
E35	507	253592	416719	163127	7	49%
W9	4720	1465905	2065735	599830	322	34%
W38	76	218398	263801	45403	11	19%
W48	421	648332	1151977	503645	341	56%
E11	6385	1442081	2173500	731419	230	40%
E10	5955	1545593	1214361	-331232	202	-24%
E30	387	211913	0	-211913	115	-200%
W20	80	369596	495643	126047	60	29%
E27	3	152642	0	-152642	2	-200%
E18_03	1555	712268	1401163	688894	238	65%
W44	504	156053	0	-156053	5	-200%
W7_02	10	26241	0	-26241	16	-200%
FREEZONE 2	12	0	0	0	11	0%
E4_02	5949	2175571	3206370	1030799	480	38%
W2	1493	332479	760216	427737	67	78%
W28	79	218799	0	-218799	42	-200%
W45	11	122314	22792	-99522	8	-137%
W10	5375	1142772	1270572	127801	86	11%
W43	5	127066	59321	-67745	6	-73%
E9_01	908	471273	244678	-226595	32	-63%
W17_02	317	334256	543121	208865	244	48%
E42	7	61131	105152	44021	8	53%
E16_02	3766	950556	1636329	685773	139	53%
W12	562	286770	169990	-116780	199	-51%
E4_01	10932	4212885	-25052900	-29265785	317	281%
KASSER AL AMWAJ	542	1214250	1045357	-168893	188	-15%
W36	82	118896	-1	-118897	58	-200%
E39	350	137575	329411	191836	107	82%

W59_01	877	1025311	1081351	56040	37	5%
W69	5	30618	656790	626172	1	182%
E9_02	5114	1289286	-133818	-1423104	200	-246%
W53	5	1020073	93959	-926114	4	-166%
E2	2345	680655	0	-680655	33	-200%
FREEZONE	365	845971	1716965	870994	350	68%
W35	1230	844403	0	-844403	49	-200%
W41	10	351664	382103	30439	15	8%
W50	129	2068302	1835531	-232771	114	-12%
W8	2459	747689	939037	191348	80	23%
E16_01	2393	580802	1327466	746664	130	78%
W52	416	2090694	2301308	1376476	308	10%
W14_01	557	1698206	2395258	697052	466	34%

Abu Dhabi Island Interface Points and Sector measuring points

The table no. 2 below shows the number of interface points of Abu Dhabi Island, in which the interface supply data had been integrated with the relevant interface points so that it is georeferenced. The same procedure was done to the Sector measuring points in order to spatially and accurately link the monitored flow data with the relevant sector's meter. Figure 4 and figure 5 as well as table 2 and table 3 below presents the data of interface points and sector measuring points data respectively.

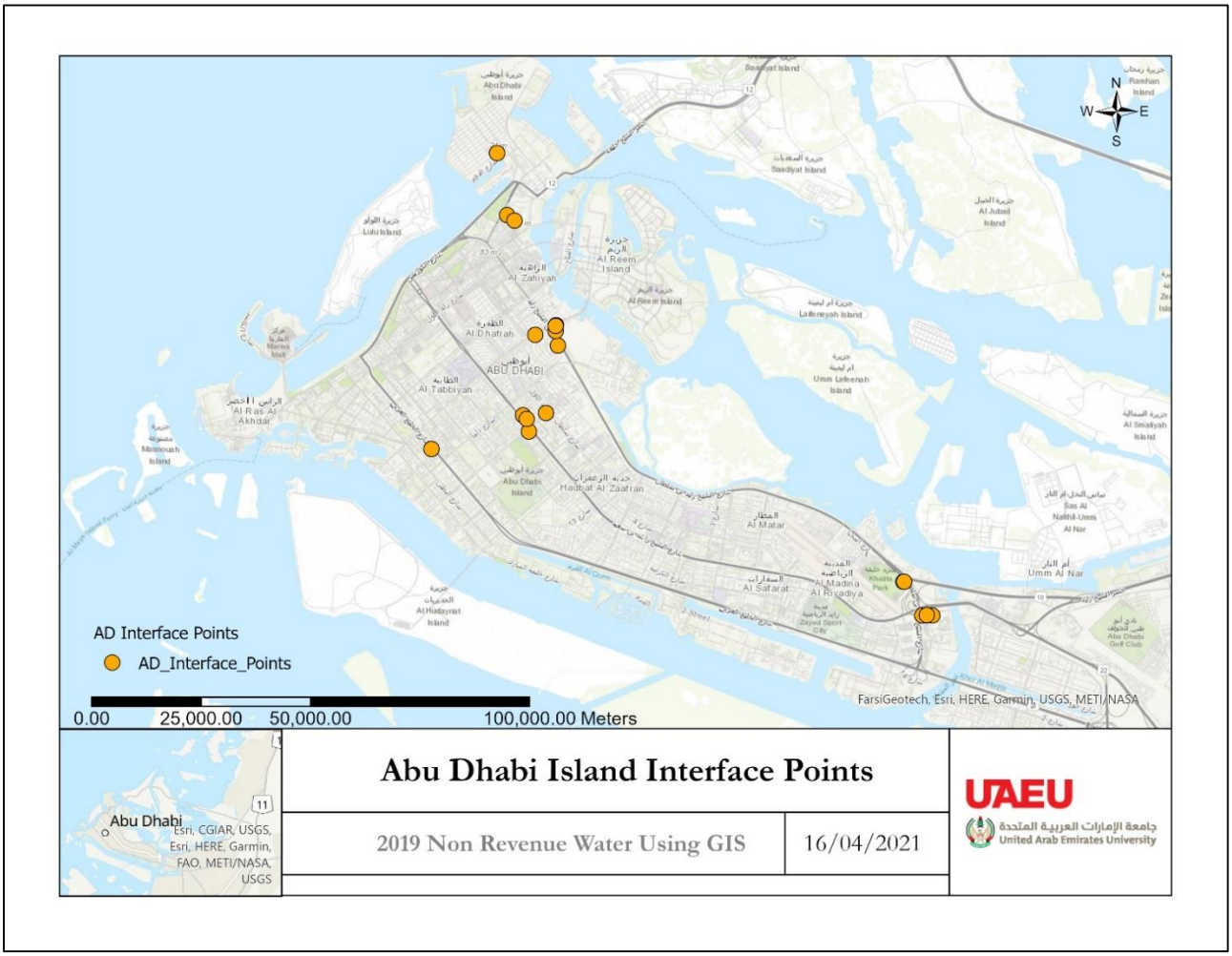

Figure 4: Interface Points – Source of Supply

Table 2: Interface Points with associated data

FACILITYID	Supply M3/Y
AD 30	2,523,114.00
AD 12	-
AD 20	21,561,029.00
AD 10	21,212,455.00
AD 21	-
AD 3	11,400,637.00
AD 15	2,109,657.00
AD 9	1,631,249.00
AD 16	172.00
AD 17	3,854,678.00

FACILITYID	Supply M3/Y
AD 4	7,737,640.00
AD1	-
AD 5	12,186,505.00
AD 2	16,674,273.00
AD13	3,146.00
AD 8	2,165,178.00
AD 14	-
AD 11	32,950,378.00
AD 6	10,280,484.00

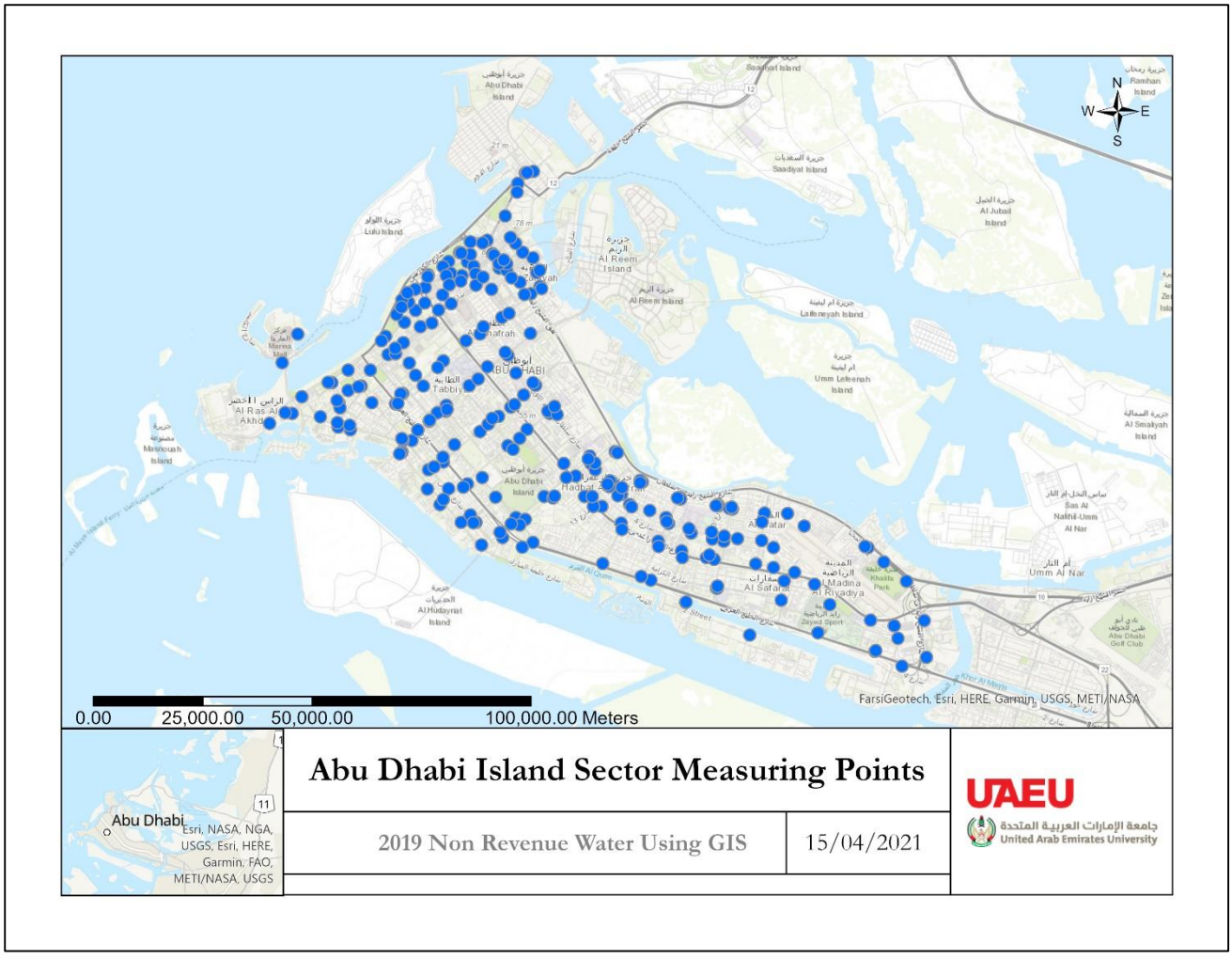

Figure 5: Sector Measuring Points distribution

Table 3: Sector Measuring Points Flow data

Sector Name	Meter No.	Monitored Flow M3/Y
W59	959302H302	520794.16
W27	935502H291	-180442.94
W22	990702H341	-168.21
W22	966202H322	493511.06
E48	989702H341	664317.06
E48	991102H341	155278.54
E48	987102H341	1396.52
E48	994002H341	1017360.58
W20	930502H291	0.00
E48	990402H341	0.00
E48	992702H341	836324.52
E25	994502H341	1126704.27
E34	929202H291	0.00
E34	932202H291	275956.76
E31	930102H291	392355.09
E9_02	955302H272	300738.94
E9_02	992402H341	400.73
W27	934902H291	0.00
E1	992202H341	659389.09
W23	933202H291	2.44
E38	928902H291	574309.79
E38	934702H291	841745.20
W29	954202H272	-0.09
E39	936402H291	-0.72
W29	909202H082	46.47
E29	954802H272	192572.94
W29	929302H291	245492.50
W69	934302H291	656790.19
E1	985802H341	277659.90
E5	995102H341	0.00
E8	965802H322	-111445.12
E3	994602H341	1340862.98
E9_02	931102H291	12719.93
W50	989502H341	1275390.52
W52	931502H291	370207.99
E03	960002H302	-15314.06
E6	960102H302	704585.73
E27	930702H291	0.00
E21	931402H291	671791.14
E22	960502H302	1164782.83
W65	928502H291	9667.25
W46_02	985902H341	1438416.69

Sector Name	Meter No.	Monitored Flow M3/Y
E40	929502H291	9862.37
E43	934102H291	142099.79
E41_01	930402H291	0.00
E41_01	961202H302	190571.64
W34	966002H322	472064.25
W31	989302H341	0.00
W34	934002H291	-582439.57
E5	928702H291	814963.16
E9_01	909802H082	244684.17
E16_02	987802H341	0.00
E7	987502H341	203839.16
E25	989202H341	0.00
E8	965702H322	671418.31
W23	993002H341	1649300.56
E8	986702H341	147312.79
E18	961702H302	1794578.02
E18_01	994402H341	0.00
W02	955702H272	237543.90
W12	985702H341	169989.82
W6	955402H272	0.00
E4_02	910402H082	971587.75
W07	929402H291	49326.76
W04	988802H341	741842.84
W02	991502H341	522653.64
E4_01	993602H341	1664558.24
E4_01	988502H341	-26717458.30
E4_02	994902H341	2234782.49
W8	995402H341	934448.15
W10	988002H341	0.00
E18_01	961302H302	-2686299.14
E18_02	948302H291	17483.72
E16_02	910102H082	1636328.73
E11	992802H341	1289306.21
E11	960602H302	-24.58
E11	960902H302	884218.43
E16_01	993402H341	212940.30
E11	988202H341	0.00
E16_01	991702H341	601997.83
E11	936502H291	0.00
W52	987302H341	0.00
W9	991902H341	1676233.58
W9	909902H082	4.32

W53	930902H291	93958.86
W52	990602H341	1931100.53
W20	928602H291	495642.80
W37	954702H272	-24643303.78
E9	989002H341	-6.23
W7_01	907202H082	-1.55
W16	994802H341	861270.04
E17	934402H291	204621.55
E31	932402H291	0.00
E31	933702H291	0.00
W15_02	932802H291	0.00
W04	990802H341	2178444.00
E19_02	990202H341	388.86
E19_02	995902H341	1873221.38
E26	937802H291	398945.08
E26	907502H082	0.00
E16	908802H082	210381.90
E16	908402H082	686530.74
E16	993102H341	1157926.65
E48	993202H341	0.00
E31	987002H341	494907.31
W59	990102H341	1081358.29
W59	988902H341	635569.62
W15_02	960702H302	902366.73
W46_01	907302H082	-8042.90
W17_03	936102H291	489021.78
W17_02	933002H291	543183.39
W17_01	932302H291	-96.04
W15_01	937202H291	676554.25
W25	928302H291	361176.05
W13	908402H432	1380724.15
W18_03	960202H302	1.62
W18_03	933802H291	3791.73
W15_01	985602H341	0.00
E19	989102H341	1934864.42
W15_02	907002H082	216269.71
E12	995202H341	938756.53
E10	908602H082	0.00
E18_03	989402H341	19.19
E18	909602H082	1401143.54
E29	936602H291	352539.78
E27	930802H291	0.00
E43	933902H291	288177.99
E28	933302H291	249347.22

W9	966102H322	389496.97
W02	988702H341	18.24
W05	992002H341	1064202.08
W05	928402H291	0.00
W18_01	992902H341	890822.59
W18_01	955202H272	-12317377.60
W18_02	909302H082	946080.00
W59	936802H291	-7.26
W01	932502H291	108745.82
W01	986302H341	170262.54
W52	937302H291	-0.14
W6	956002H272	567122.95
W10	988602H341	1270572.42
W11	959502H302	22492.98
W05	937402H291	4515249.97
W12	933102H291	0.00
E12	991202H341	887091.71
E14	989602H341	421085.52
E14	988302H341	755113.03
E14	959202H302	164614.23
E15	995302H341	835159.80
E13	994202H341	1628700.90
MZ	989802H341	4.61
M2	993702H341	1716960.00
E20	930602H291	0.00
E20	986902H341	16426.92
E20	935602H291	0.00
W62	994102H341	845091.13
W36	936902H291	-0.61
W64	929102H291	467820.71
W66	929802H291	0.00
E7	909002H082	283987.65
E3	990002H341	308.53
E03	994302H341	1790757.58
W17_01	965602H322	-28632.96
E21	933602H291	-23694.85
E21	909702H082	0.00
E22	910202H082	-50.63
E24	931002H291	112161.13
E36	909102H082	-4999.79
E25	995602H341	7738.83
E25	910502H082	879434.89
E34	988402H341	59551.49
E36	909402H082	193302.21

E28	955102H272	-54643.06
E29	931702H291	10221.59
E30	929702H291	0.00
E32	987202H341	530569.85
E33	937002H291	0.00
E35	955902H272	0.00
E35	937502H291	416523.32
E41	932902H291	1060594.86
E49	995702H341	49641.52
E37	928202H291	905600.87
E40	908002H082	445690.47
E43	932002H291	-0.14
E41	935002H291	967661.78
E42	929602H291	105151.83
W13	990502H341	840842.16
E15	934202H291	477212.44
W21	991002H341	45072.99
W48	990302H341	-11503.00
W48	986202H341	383840.83
W47	989902H341	9000.65
W47	993502H341	0.00
W11	994702H341	169557976.41
W46	937602H291	-146.29
W21	988102H341	0.00
W52	987402H341	0.00
W56	992102H341	194706.27
W36	936002H291	0.00
W37	908502H082	1658.85
W38	937702H291	263801.19
W39	965902H322	0.00
W41	908702H082	382103.02
W42	934602H291	0.00
W43	959402H302	59320.52
W45	934802H291	22791.90
W48	986802H341	779638.97
W08	986002H341	4588.38
W13	959902H302	0.00
W14	992502H341	489359.54
BW	961102H302	415086.01
BW	960402H302	630270.69
W32	954602H272	71729.87
W66	987702H341	-75986631.00
W14	995002H341	14076.64
W62	960302H302	1835273.64
E36	955802H272	804367.66
E36	932602H291	262276.01
E36	955002H272	13227.40
E43	986102H341	0.00
E10	966302H322	1214361.10
E10	937102H291	0.00
W17_02	930002H291	339836.84
E9_02	908102H082	-447677.97
W05	928802H291	0.00
E34	936702H291	0.00
E33	932102H291	9.84
E35	935202H291	195.65
W51	934502H291	-71.55
E39	930302H291	329411.40
W23	992602H341	-240.10
W7_01	987602H341	973375.93
E06	910002H082	0.00
W62	961602H302	665052.96
W28	935902H291	0.00
W32	955602H272	229033.69
E16_01	986502H341	512527.86
W13	961002H302	-45258.52
W17	986402H341	0.00
W23	935702H291	134489.02
W26	929002H291	-0.21
W30	W30	1732876.11
W30	930202H291	1027723.78
W50	929902H291	560140.16
W57	936302H291	317535.26
W57	993802H341	409528.76
E38_01	990902H341	-48293.70
W16	993302H341	-3.73
W14	961502H302	732970.40
W17_03	933502H291	0.00
W16	995502H341	362655.42
E48	991302H341	-4.79
W14	961402H302	1158851.55
W24	991802H341	1014705.52
W24	959802H302	0.00
W25	931202H291	0.00
W25	931902H291	137435.75
W25	931802H291	-7.05
W56	931302H291	-454.95
E41_01	991402H341	14.40

Connection points and service points per Sector

The connection points represent the point of connection between customer property and distribution network. Contrary, the service point represents the meter related to the consumption data. One connection point may have one or more service points. Both of these data were captured and integrated with the relevant sector as shown in the figure no. 6 and figure no. 7.

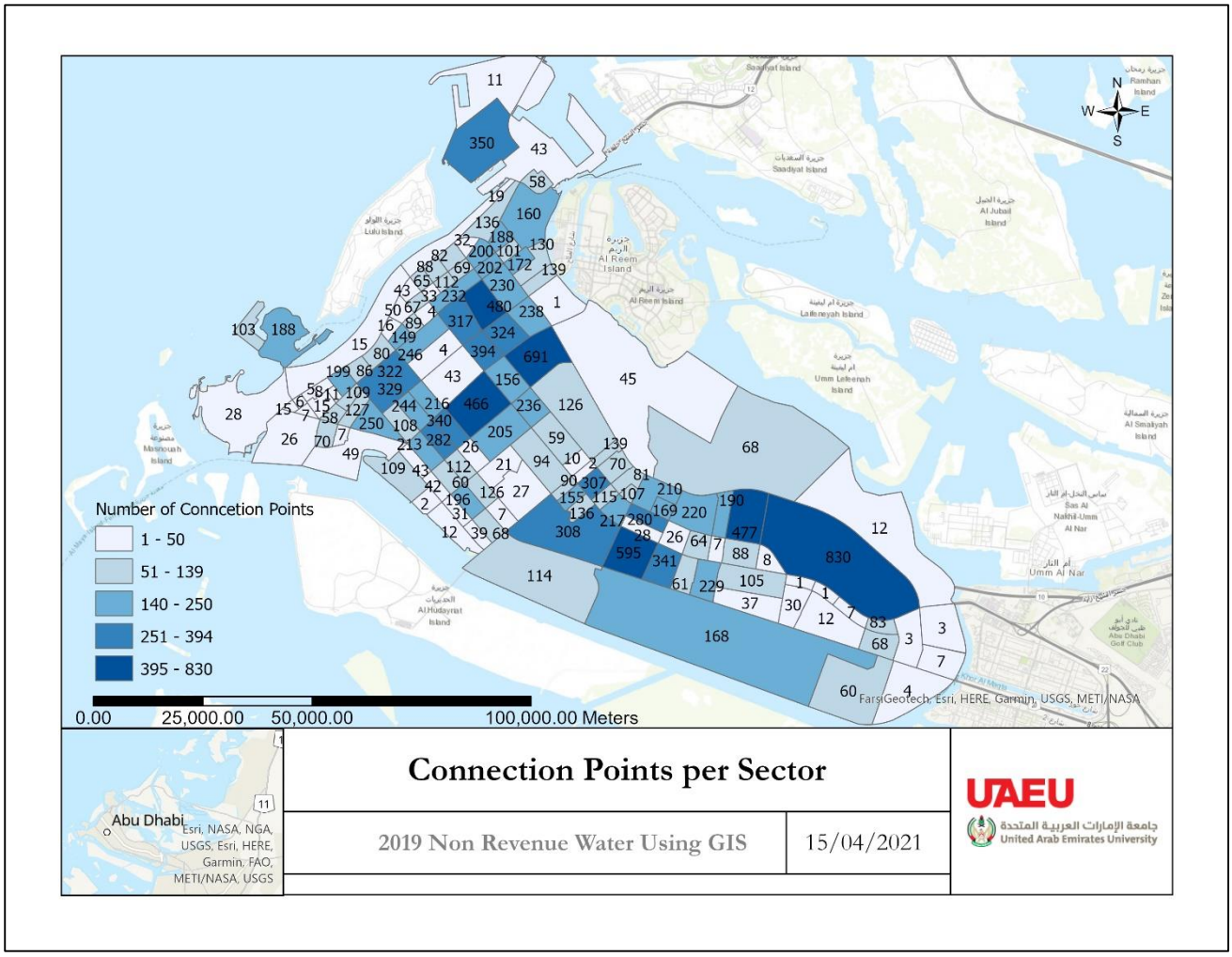

Figure 6: Connection Points per Sector

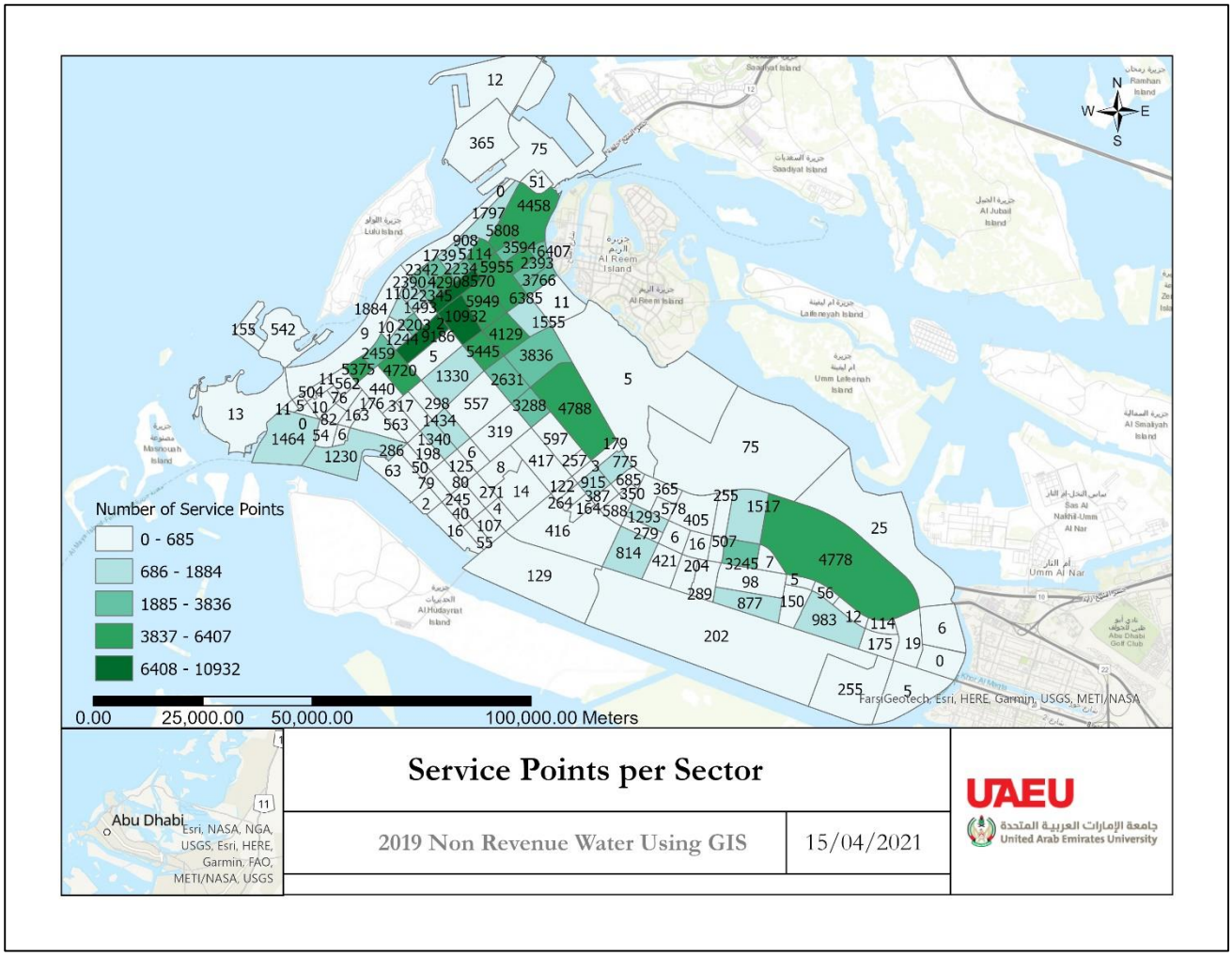

Figure 7: Service Points per Sector

Sectors with Non-Revenue Water below or equal to 12% and greater than 12%

The layer was created to visualize and further analyse the sectors with non-revenue water below or equal to 12% which represents about 11% of the total sectors within Abu Dhabi Island. Figure no. 8 and table no. 4 presents the data related to these sectors.

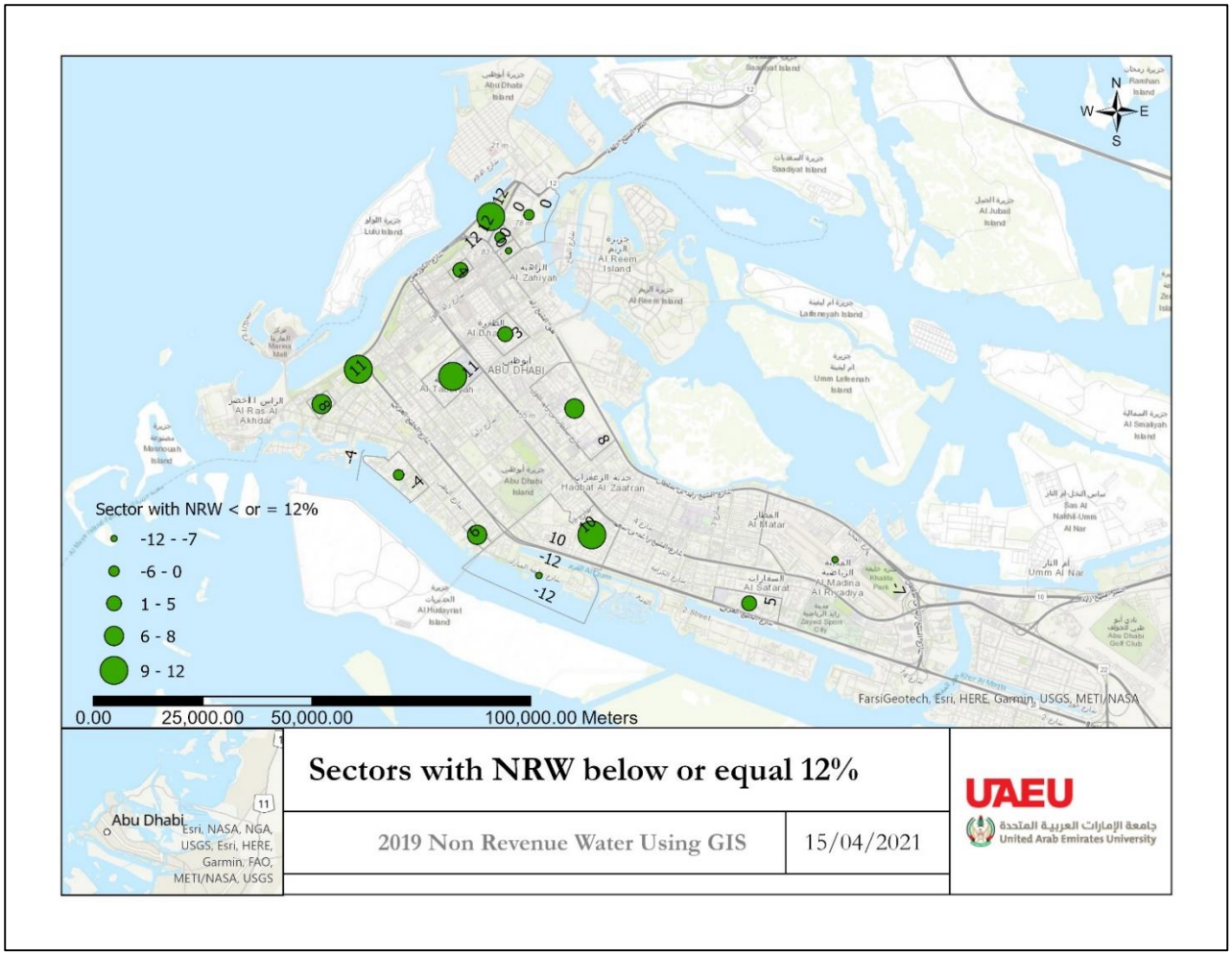

Figure 8: Sectors with NRW below or equal 12%

Table 4: Sectors with NRW equal or below 12%

NAME	Consumption M3/Y	Monitored data M3/Y	NRW M3/Y	2019 NRW Percentage
E25	1859962	2013878	153916	8%
E12	1613332	1825848	212516	12%
E18_02	1754115	1812062	57947	3%
E8	676445	707286	30841	4%
E13	1634230	1628701	-5529	0%
W25_01	128823	137436	8613	6%
E48	2877399	2674672	-202727	-7%
E15	1413992	1312372	-101620	-7%
W30	2874315	2760600	-113715	-4%
E14	1176199	1176199	0	0%
W13_01	1942329	2176308	233979	11%

W10	1142772	1270572	127801	11%
W59_01	1025311	1081351	56040	5%
W41	351664	382103	30439	8%
W50	2068302	1835531	-232771	-12%
W52	2090694	2301308	1376476	10%

The layer was created to visualize and further analyse the sectors with non-revenue water greater than 12%. The same account for about 89% of the total sectors in Abu Dhabi Island. Figure no. 9 and table no. 5 presents the data related to these sectors. where values of NRW is negative means that the consumption is higher than the monitored flow and that could be caused by data inaccuracy, in which the consumption is linked with a wrong sector. On the other hand, where the values of NRW is positive, means that the monitored data is higher than the consumption data. The factors contributing to that may be the same reason above or the sector point supplying more than one sector during the year due to operational matters. Due to the fact that the percentage of the sectors with an NRW greater than 12%, NRW management activities shall be seriously considered to actively bonds the gap between the consumption and monitored flow and that could be achieved by integrating the customer meter location (x and y coordinates) in the GIS so that it is georeferenced correctly with the relevant sector. Another activity is identifying the precise number of properties within each sector so that the properties without consumption record could be easily found and equipped with meter and/or estimated consumption based on customer category. Moreover, reliable metering of water volumes is essential for reliable assessment of water losses. Thus a regular metering maintenance and calibration shall be undertaken for both consumption meters and sectors' flow meters.

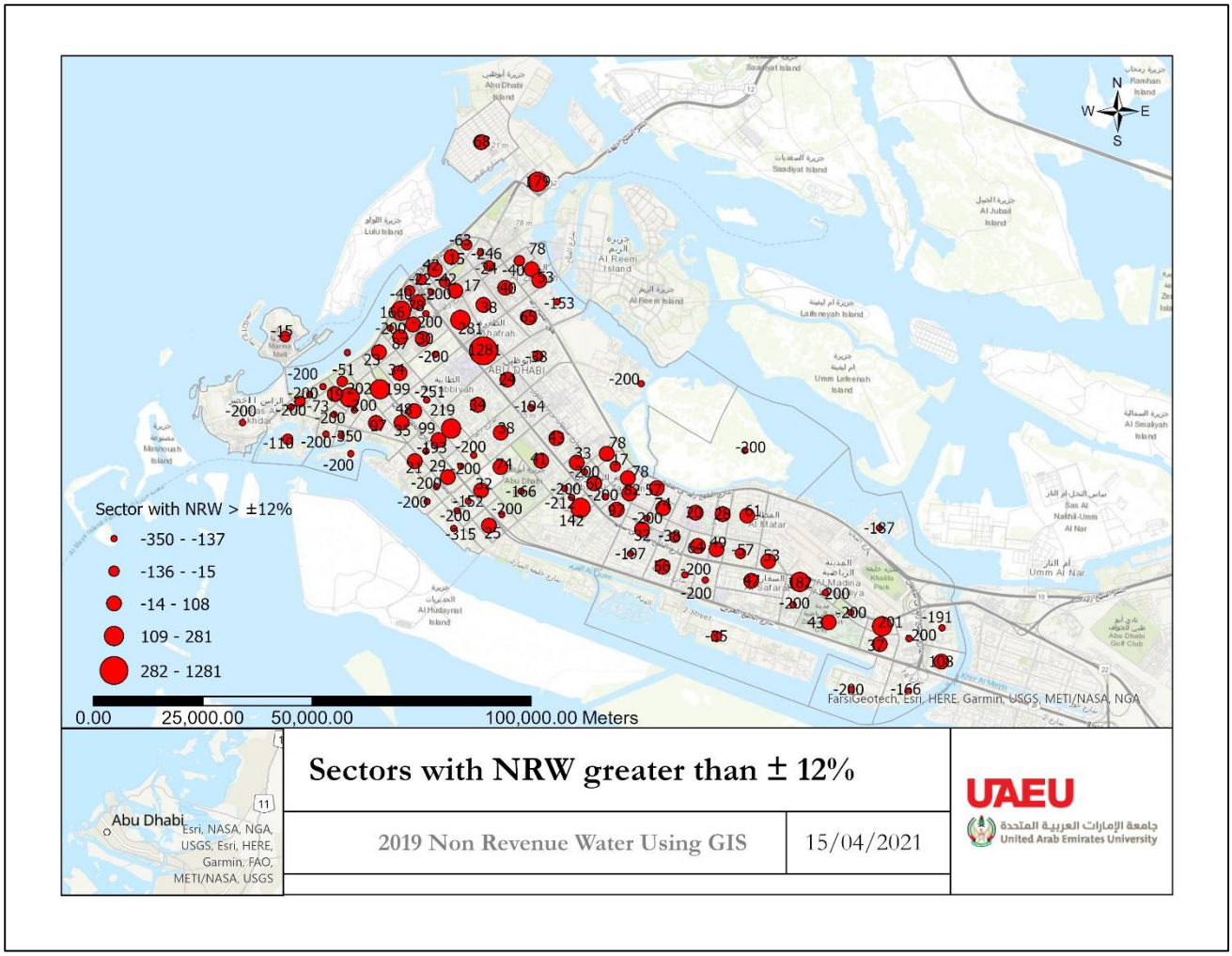

Figure 9: Sectors with NRW greater than ± 12%

Table 5: Sectors with NRW greater than ± 12%

NAME	Consumption M3/Y	Monitored M3/Y	NRW M3/Y	2019 NRW Percentage
W27	169735	0	-169735	-200%
E31	308764	887262	578498	97%
W65	424826	9667	-415159	-191%
W18_02	435413	1285917	850504	99%
E41	1181168	2218843	1037675	61%
W46	258439	-146	-258585	-200%
W56	134201	194251	60050	37%
E18_01	1960759	-2686299	-4647058	1281%
W19_01	427818	0	-427818	-200%
W33	100808	0	-100808	-200%
W17_03	344085	489022	144937	35%
W54	1247971	0	-1247971	-200%
W68	175501	0	-175501	-200%
W46_01	275037	-8043	-283080	-212%
W34	403766	-110375	-514141	-350%
E16	3088568	2054839	-1033729	-40%

E36	1041855	1268173	226318	20%
E5	531925	814963	283038	42%
W58	798028	0	-798028	-200%
E19_02	2751658	1873610	-878048	-38%
E19	1514377	1934864	420487	24%
E29	243254	555334	312080	78%
E23	80587	112161	31574	33%
W28_01	379650	0	-379650	-200%
W62	4767509	3345418	-1422091	-35%
W46_02	244444	1438417	1193973	142%
E1	1166042	937049	-228993	-22%
E26	174796	398945	224149	78%
E33	428776	10	-428766	-200%
E7	418271	487827	69556	15%
W24_01	671405	1014706	343301	41%
E17	1530717	204622	-1326095	-153%
W23	756929	1649303	892374	74%
W25	282110	361169	79059	25%
W18_03	209579	3793	-205786	-193%
W1_01	49518	0	-49518	-200%
W42	4826471	0	-4826471	-200%
E38	759512	1367761	608249	57%
W16	425275	1223922	798647	97%
E20_01	1039232	16427	-1022805	-194%
E40	821199	455553	-365646	-57%
E32	383071	530570	147499	32%
W17_01	256208	-28729	-284937	-251%
E14_01	9097	164614	155517	179%
W31	497831	0	-497831	-200%
W1	418037	279008	-139029	-40%
W22	358293	493343	135050	32%
W21	332636	45073	-287563	-152%
W47	1148004	9001	-1139003	-197%
W29	198754	245539	46785	21%
W23_01	1422351	134249	-1288102	-166%
W5	511450	5579452	5068002	166%
E6	1084332	704586	-379746	-42%
W39	279798	0	-279798	-200%
W4_01	350290	0	-350290	-200%
W7_01	385175	973374	588199	87%
E34_01	87126	59551	-27575	-38%
AL GARM	308887	0	-308887	-200%
W51	780744	-72	-780816	-200%
E37	415716	905601	489885	74%
W67	113747	0	-113747	-200%

W19_02	772806	0	-772806	-200%
W49	312115	0	-312115	-200%
W11	444947	169580469	169135522	199%
E22	751434	1164732	413298	43%
E49	1446996	49642	-1397354	-187%
RAS AL AKHDAR	1771659	0	-1771659	-200%
W18_01	511594	-11426555	-11938149	219%
E34_02	142293	275957	133664	64%
W37	152986	-24641645	-24794631	202%
QASR AL BAHR	51062	0	-51062	-200%
W57	472049	727064	255015	43%
E21	348266	647405	299139	60%
E28	231882	194704	-37178	-17%
W26	360975	0	-360975	-200%
W6	480538	567123	86585	17%
W59_02	718348	1156364	438016	47%
W66	159588	-75986631	-76146219	201%
W32	1041802	300764	-741038	-110%
W15_01	1228105	1795191	567086	38%
W3	81135	0	-81135	-200%
E3	2619638	3116615	496977	17%
W64	139117	467821	328704	108%
E43	324234	430278	106044	28%
W4	2160235	2920287	760052	30%
W27_01	809500	-180443	-989943	-315%
E35	253592	416719	163127	49%
W9	1465905	2065735	599830	34%
W38	218398	263801	45403	19%
W48	648332	1151977	503645	56%
E11	1442081	2173500	731419	40%
E10	1545593	1214361	-331232	-24%
E30	211913	0	-211913	-200%
W20	369596	495643	126047	29%
E27	152642	0	-152642	-200%
E18_03	712268	1401163	688894	65%
W44	156053	0	-156053	-200%
W7_02	26241	0	-26241	-200%
E4_02	2175571	3206370	1030799	38%
W2	332479	760216	427737	78%
W28	218799	0	-218799	-200%
W45	122314	22792	-99522	-137%
W43	127066	59321	-67745	-73%
E9_01	471273	244678	-226595	-63%
W17_02	334256	543121	208865	48%
E42	61131	105152	44021	53%

E16_02	950556	1636329	685773	53%
W12	286770	169990	-116780	-51%
E4_01	4212885	-25052900	-29265785	281%
KASSER AL AMWAJ	1214250	1045357	-168893	-15%
W36	118896	-1	-118897	-200%
E39	137575	329411	191836	82%
W69	30618	656790	626172	182%
E9_02	1289286	-133818	-1423104	-246%
W53	1020073	93959	-926114	-166%
E2	680655	0	-680655	-200%
FREEZONE	845971	1716965	870994	68%
W35	844403	0	-844403	-200%
W8	747689	939037	191348	23%
E16_01	580802	1327466	746664	78%
W14_01	1698206	2395258	697052	34%

Analysis

Performing the non-revenue water analysis using GIS, found that the total non-revenue water by finding the difference between the total sectors monitored flow and consumption is 13% as shown in the figure 10 below which represents of volume of 16,504,897 m3/year. While the total non-revenue water by finding the difference between the total system input volume (Interface points) and sectors monitored flow is 12% as shown in the figure 11 which account for 16,892,708 m3/year. Comparing the system input volume with the consumption data would results for a non-revenue water of 25%. Based on the international study conducted in 2018 that shows an average of 36% NRW for Middle East and Northern Africa in which UAE NRW% was 30%, indicates that Abu Dhabi Distribution Company invested in the NRW activities that reduce the NRW% to a level below the average level of 36% and 2018 UAE level of 30%. Abu Dhabi Island (Roland L and Alan W, 2018).

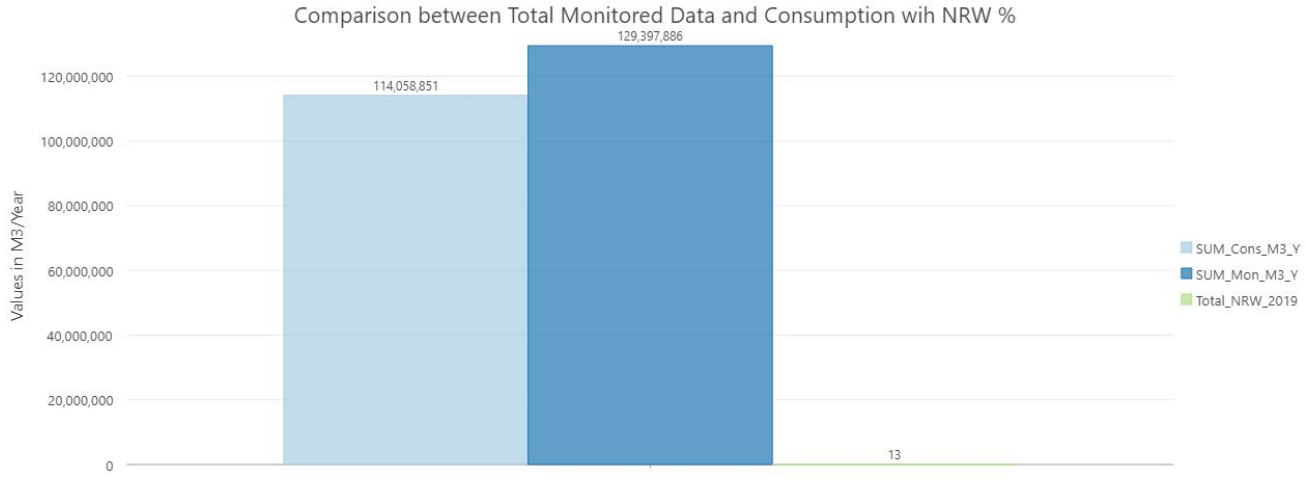

Figure 10: Comparison between total of monitored flow and consumption in m3/year with NRW%

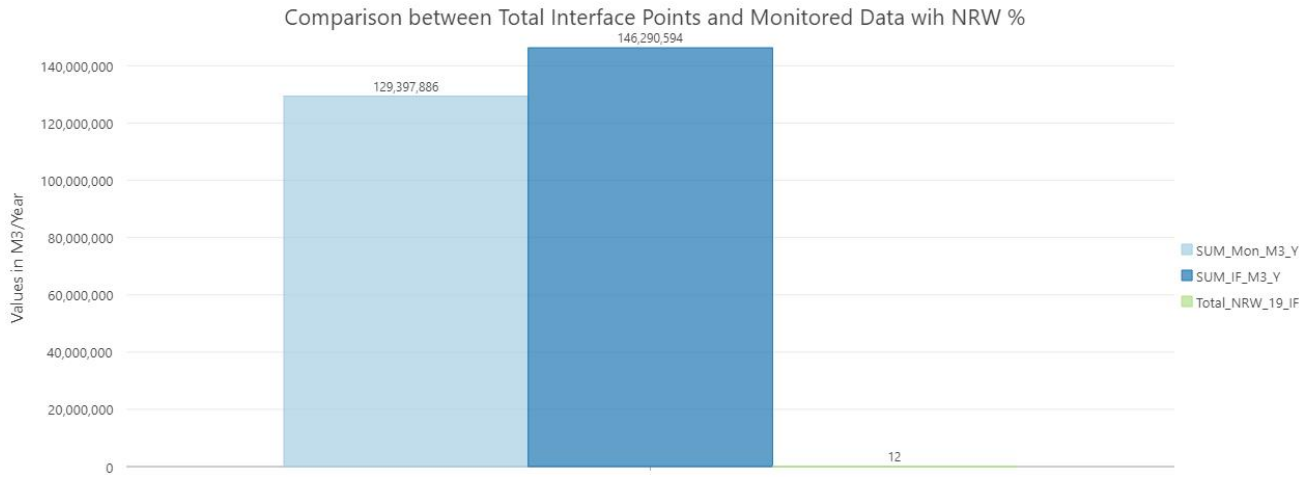

Figure 11: Comparison between total of interface flow and monitored flow in m3/year with NRW%

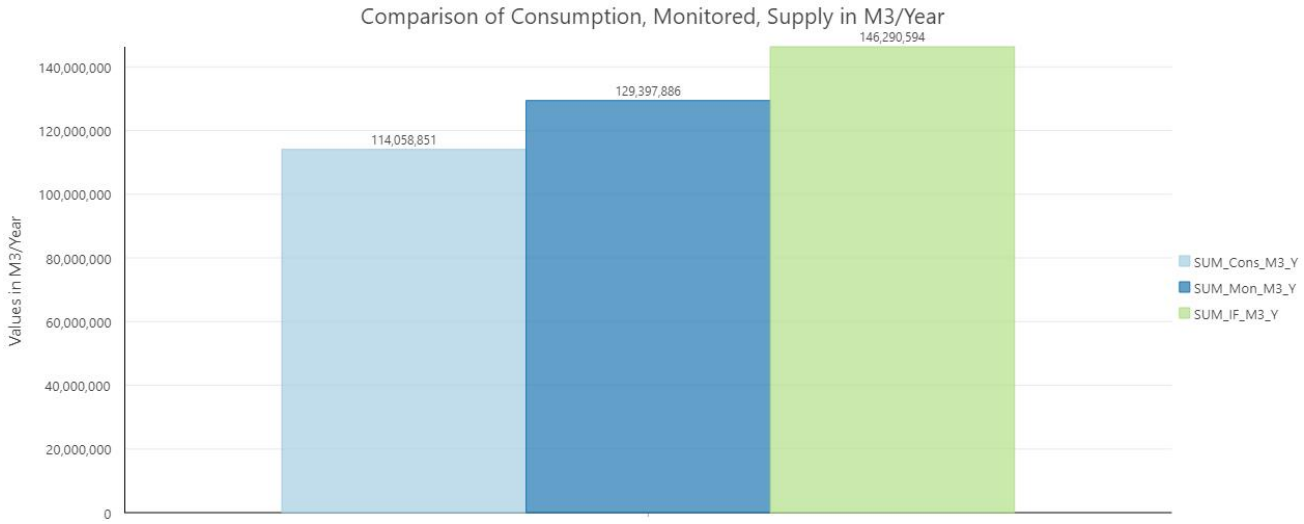

Figure 12: Comparison between total of consumption, monitored flow and Interface flow in m3/year

Monitored flow and Consumption data

The relation between the monitored flow at sector measuring point and the non-revenue water at each sector found to be positively strong (R^2=1) as shown in the figure no. 13 below. That means, when the flow increase the non-revenue water would increase. On other hand, the relation between the consumption and non-revenue water is weak (R^2 about 0) figure no. 14.

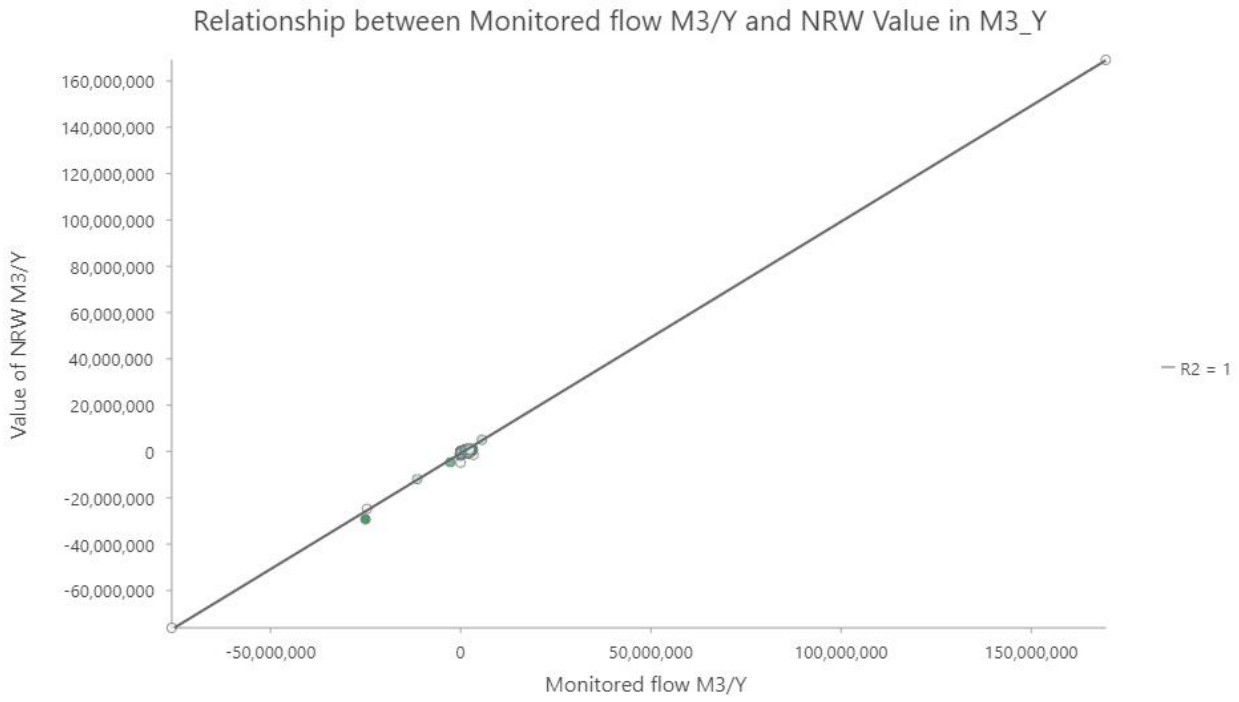

Figure 13: Relationship between monitored flow and value of NRW in m3/year

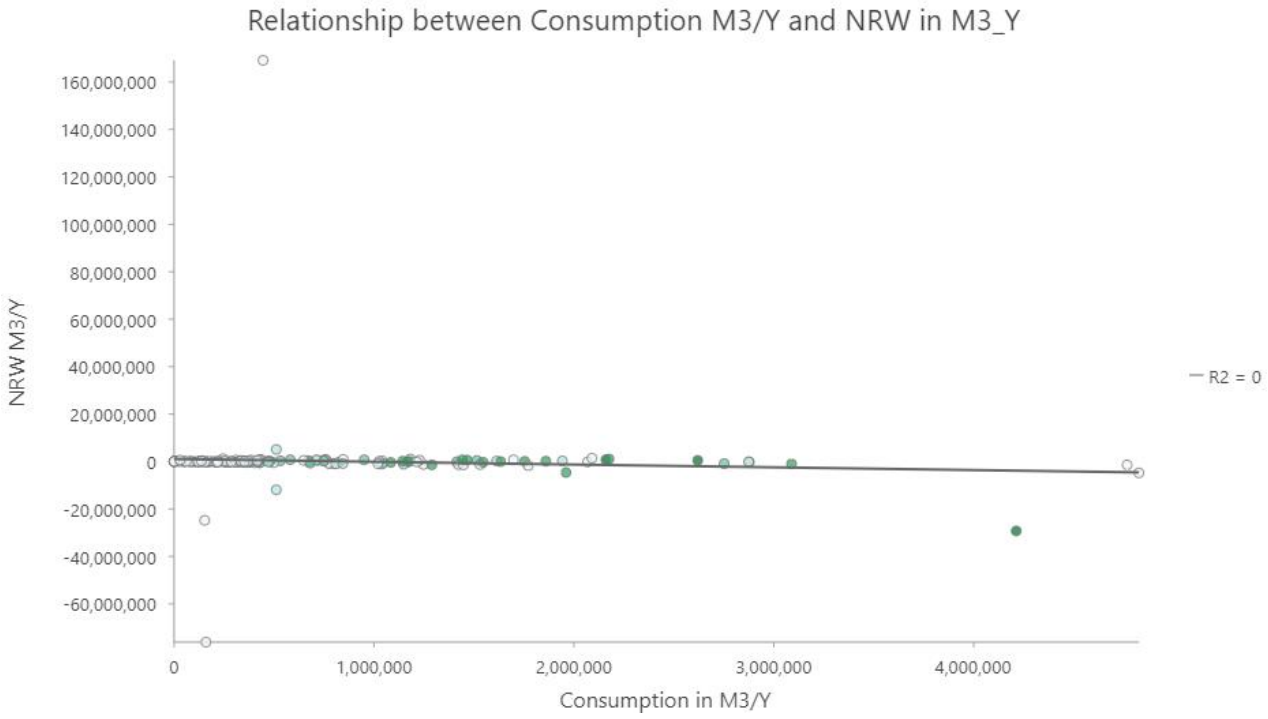

Figure 14: Relationship between consumption and value of NRW in m3/year

Number of Connection Points

The relation between number of connection points and non-revenue water at each sector found to be weak (R^2=0.09) as shown in the figure 15, which indicates that the Non-Revenue water doesn't depend only on the number of connection points, but includes other factors. These factors could be the location of the customer meter, the length of the mains, the average operating pressure, infrastructure condition, … etc., which required further analysis and investigation to categorize the non-revenue water based on the areas identified in the IWA table illustrated in figure no.1. Moreover, the relationship between the Non-Revenue water and number of connection points for the sector where the NRW is equal or below 12% found to be weak (R^2=0.12), although the NRW considered acceptable and the difference between consumption and monitored flow either small of neglectable, figure 16.

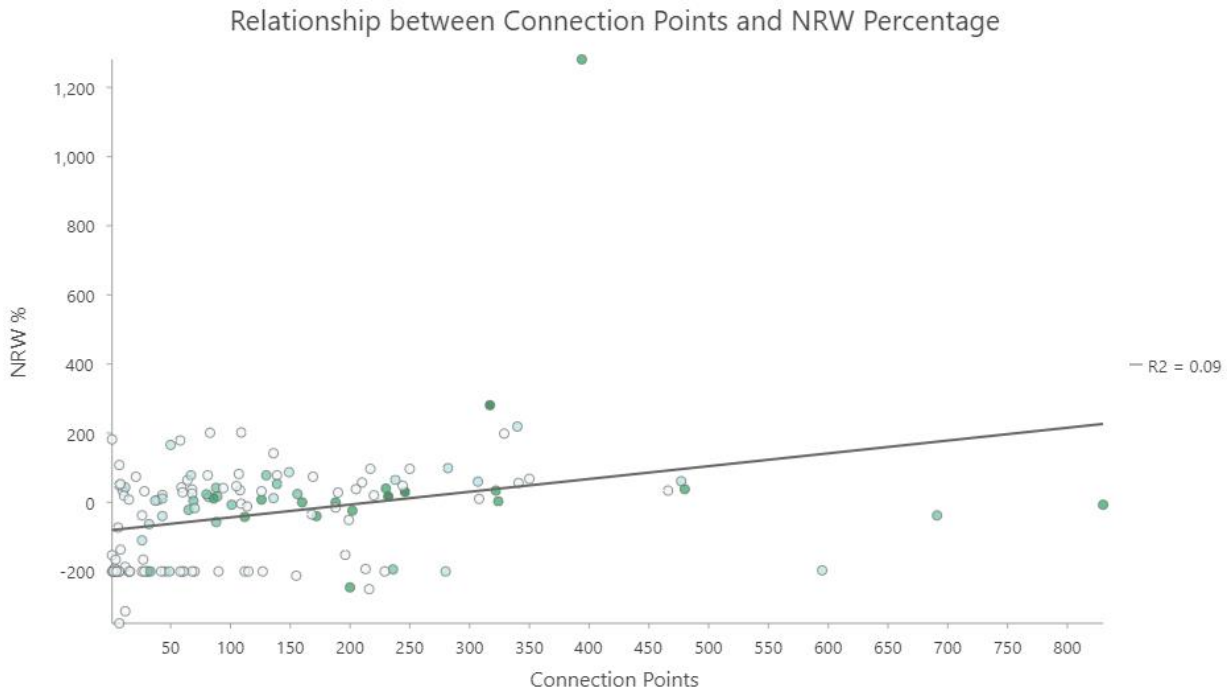

Figure 15: Relationship between number of connection points and NRW %

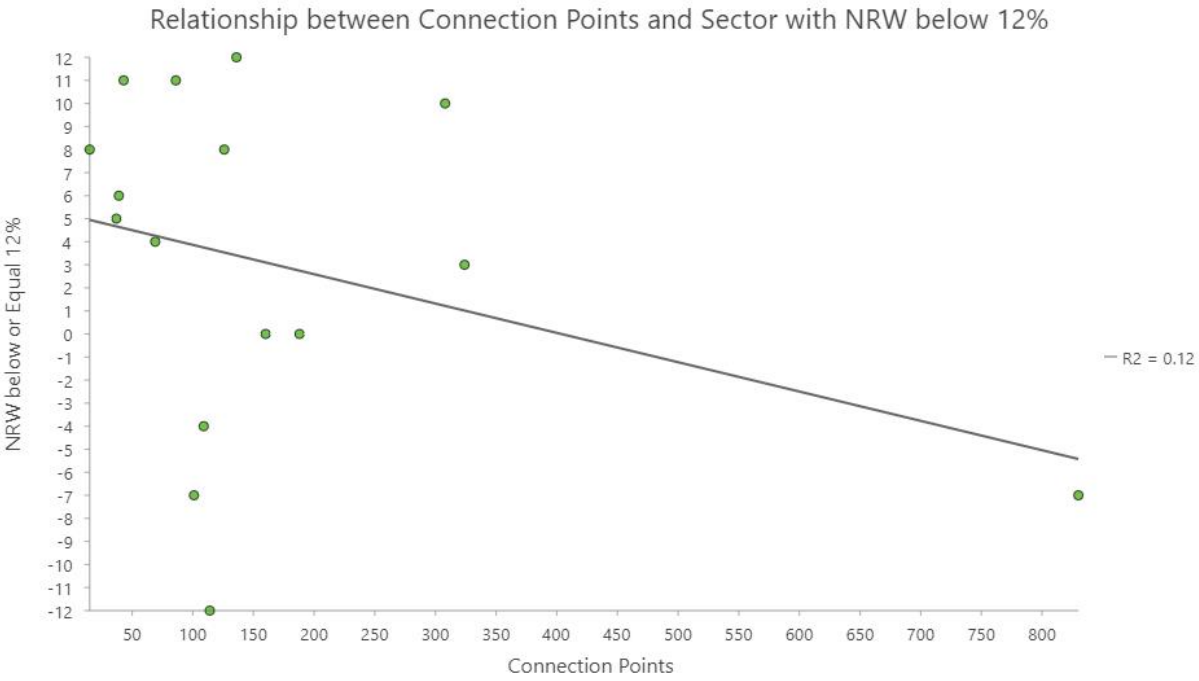

Figure 16: Relationship between number of connection points and sector with NRW below or equal 12%

2019 and 2020 Comparison

The analysis included a comparison between the values of NRW in 2019 and 2020 for selected sectors. These sectors selected based on the their NRW% in 2019 which range between 0% to above 100% as shown in the figure no. 17 below.

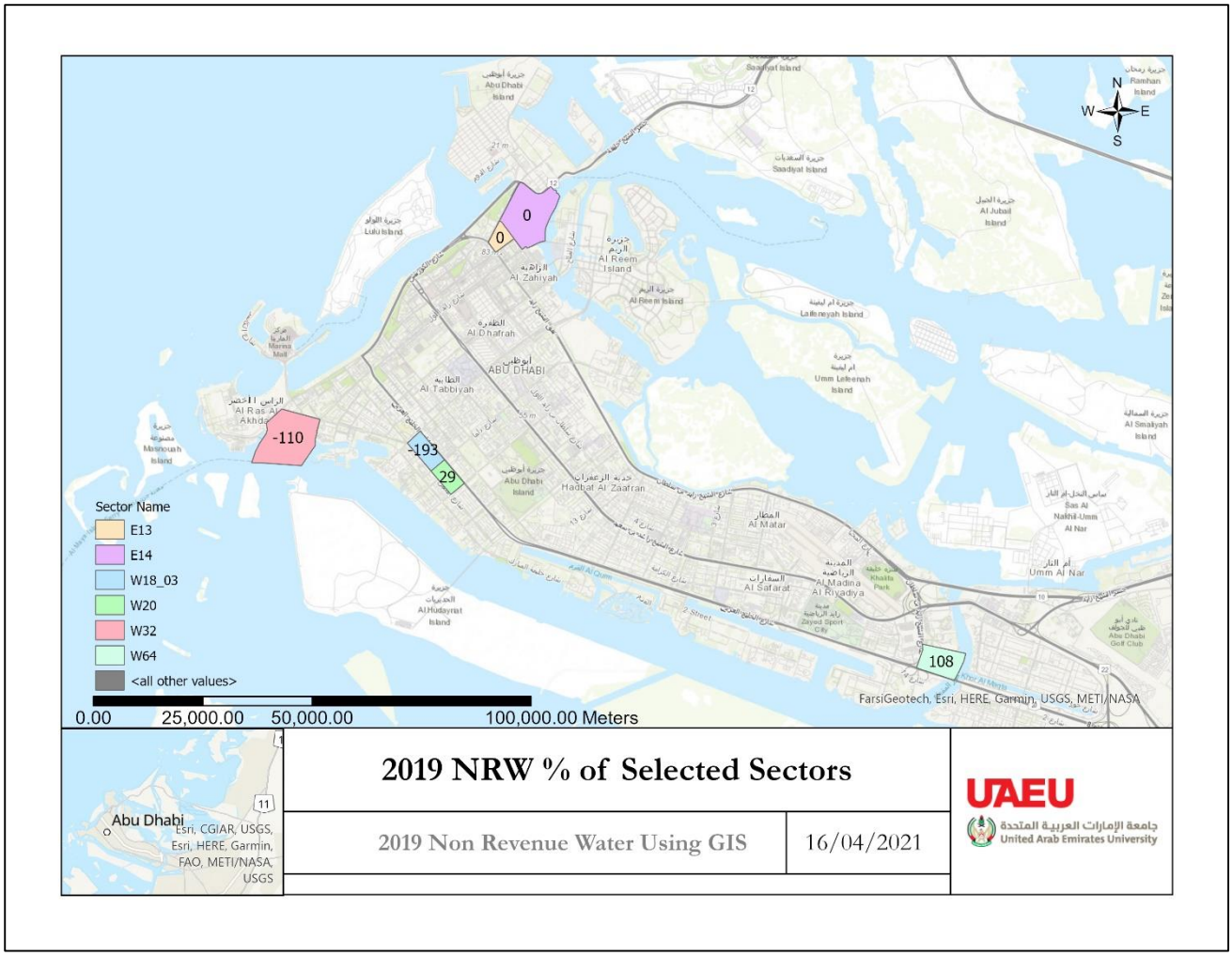

Figure 17: 2019 NRW% for selected Sectors

The figure no. 18 as well as the table 6 below illustrates the comparison between 2019 and 2020 in terms of consumption, monitored flow and NRW values in m^3/year. Moreover, the 2020 NRW% is shown in the figure 19 below against the relevant sectors. The analysis shows that 2020 NRW values and percentage is far highly than the 2019 values.

Table 6: 2019 and 2020 data

	2019				2020			
NAME	Consumption M3/Y	Monitored M3/Y	NRW M3/Y	NRW%	Consumption M3/Y	Monitored M3/Y	NRW M3/Y	NRW%
W18_03	209,579.00	3,793.00	- 205,786.00	-193%	199,909.00	3,792.00	- 196,117.00	-193%
E13	1,634,230.00	1,628,701.00	- 5,529.00	0%	1,764,506.00	1,385,689.00	- 378,817.00	-24%
E14	1,176,199.00	1,176,199.00	-	0%	2,075,734.00	1,512,633.00	- 563,101.00	-31%
W32	1,041,802.00	300,764.00	- 741,038.00	-110%	942,908.00	71,730.00	- 871,178.00	-172%
W64	139,117.00	467,821.00	328,704.00	108%	99,465.00	869,057.00	769,592.00	159%
W20	369,596.00	495,643.00	126,047.00	29%	336,754.00	-	- 336,754.00	-200%

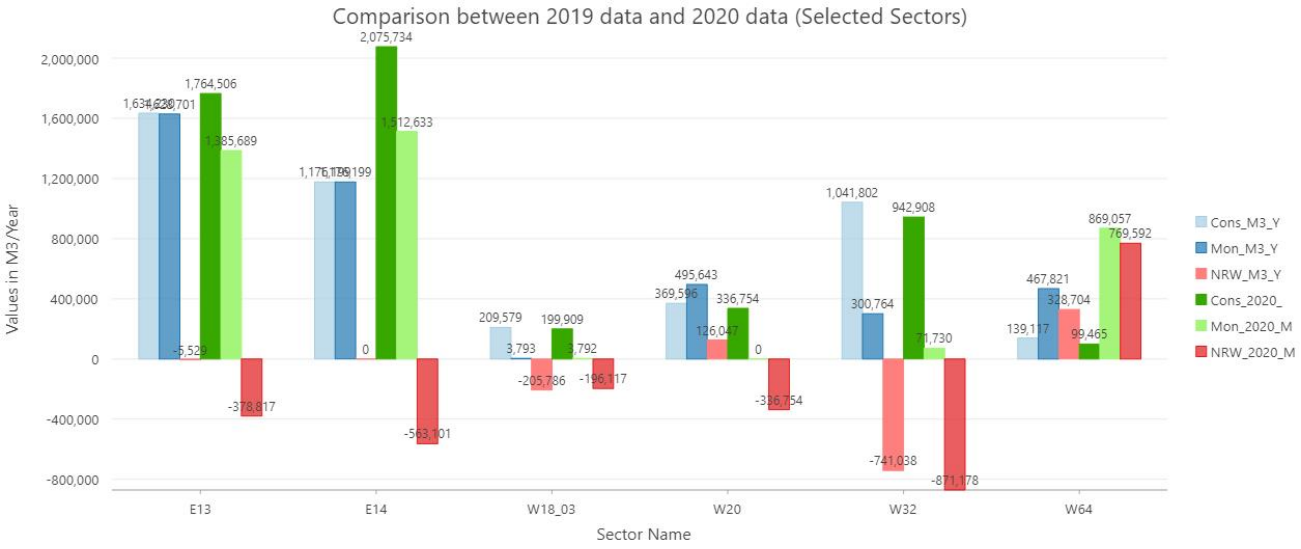

Figure 18: Comparison between 2019 and 2020 in terms of consumption, monitored flow and NRW values in m3/year

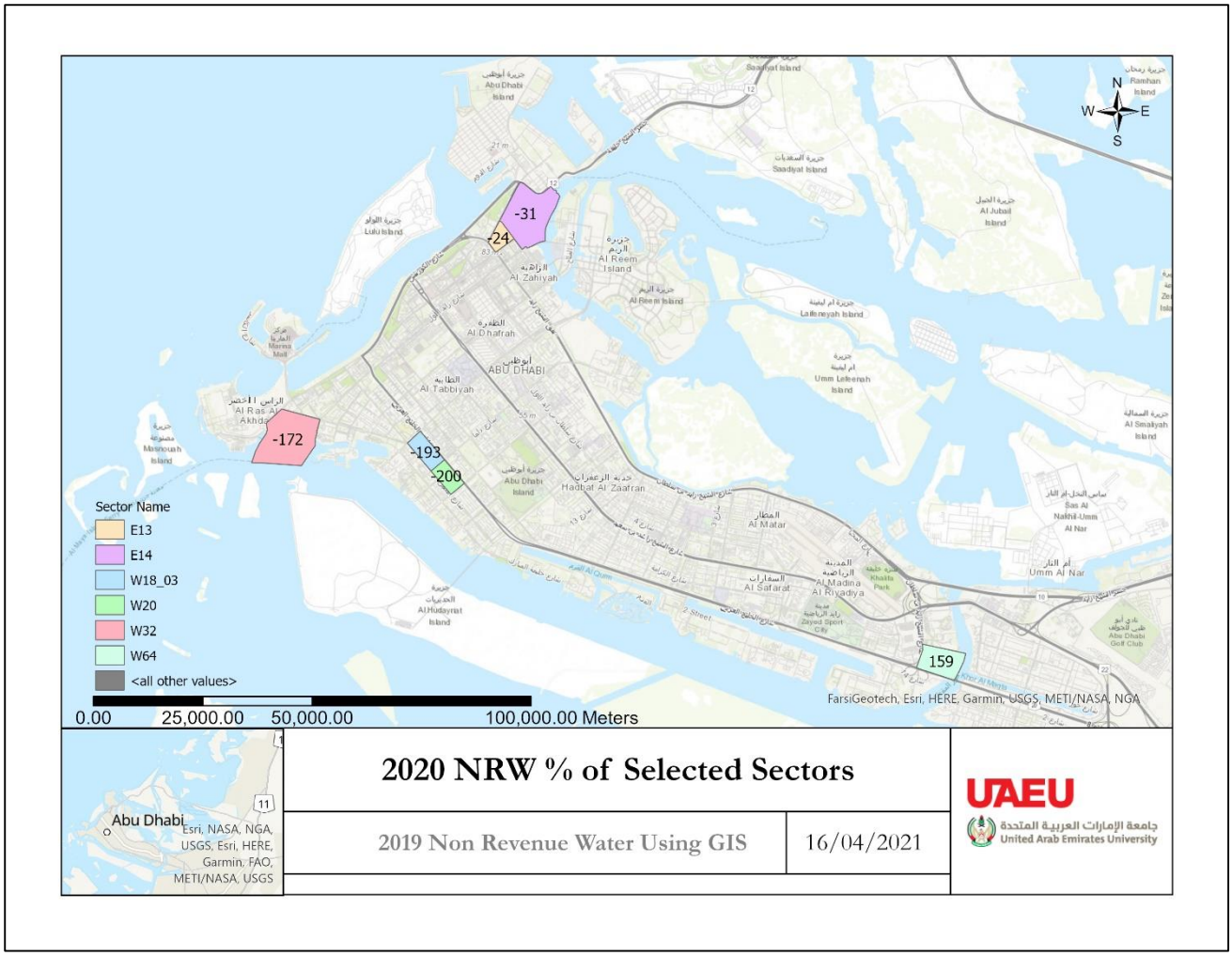

Figure 19: 2020 NRW% for selected Sectors

Conclusion and Recommendation

This paper presents utilizing GIS to integrate, map, visualize and analyze the Non-revenue water in sector wise basis against the monitored flow as well as system input volume in cubic meter per year. The integration includes data from Abu Dhabi Distribution Company GIS, Consumption system, Interface metering system, and sector measuring points data loggers' system.

Abu Dhabi Distribution Company currently calculate the IWA water balance analysis manually by comparing the system input volume against the billed consumption. The NRW in sector wise never been considered which eliminate focusing on the sectors with NRW issues and planning the correct approach accordingly.

Based on the analysis we found that ADDC is following the best international practices in designing the water distribution network. Having DMAs with well-defined inlets and outlets equipped with SMP's proper instruments for management purposes is the most essential step in the water losses reduction strategy. Moreover, following the IWA approach in calculating the annual water balance is another essential step in water losses reduction strategy.

The overall percentage of Non-revenue water found is 25% which is below the 2018 study conducted in which United Arab Emirates NRW percentage was 30% as well as lower than the average Middle East and Southern Africa NRW percentage of 36%. However, further NRW activities shall be considered to reduce the overall NRW within the Emirate of Abu Dhabi which shall put Abu Dhabi among the countries that had achieved as low as 4% NRW (Roland L and Alan W, 2018).

It is recommended to maintain an automated process of integrating GIS with other systems to ease the process of updating the GIS with the required data to perform the analysis accordingly. In addition, integrate the consumption meters with the GIS to spatially distribute the consumption against relevant sector. Review and update the number of properties within each sector to further validate consumption volume against the monitored flow. Moreover, data cleansing and validation within the consumption records shall be undertaken. Other recommendations are as follow:

1. DMAs boundaries and boundaries of interconnected DMAs:
    - There are many DMAs being supplied by one inlet, however their consumptions are separated, hence, in order to compare the consumption with inlet flow, these DMAs to be confirmed and combined in terms of analysis.
    - DMAs meters and valves details and status to be properly recorded in GIS. A virtual layer to be created for every DMAs with it is properties for ease of review and future analysis requirements.

- DMAs inlets and outlets to be well defined and reflected in the GIS to be indicated as Inlet or Outlet.
- DMAs inlets and outlets status to be well indicated in the GIS.

2. Data Loggers with unrealistic reading or zero reading to be periodically checked and maintained.
3. Billing of unbilled customers.
4. Consumption data to be validated as it includes consumption of previous years.
5. Install meters for un-metered SMPs and equip it with data loggers to get a frequent flow data.
6. Proper recording of operational modifications in the network to be reflected in GIS.
7. Regular inspections, maintenance, calibration should be carried out of SMP meters, Consumption meters, and Data Loggers.

GIS could be used as platform to perform the full process of IWA water balance analysis in order to find the Water loss percentage.

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