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Reclaimed Water Project: Effects of High Na Concentration in Soil and Plant Tissues

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Abstract: *Clark Water Corporation (CWC) intends to reclaim its treated wastewater (WW) for turf grass irrigation in golf courses and other urban landscapes. CWC's treated effluent meets the DA (DAO 26) irrigation standard except for sodium which exceed by an average of 17%; creating the need to study the effects of high Na concentration of WW in soils and plant tissues. Soil samples were compiled from 3 sites; 2 from target irrigation sites, P.Balagtas and Korea CC and 1 from the final pond of the Wastewater Treatment Plant's (WWTP) to replicate long-time irrigated soils. Soils were transferred to experimental plots, planted with foliage and irrigated for 5 months with equal amounts of WW. Results indicate that soils from the target sites are fine grained sandy soils and that WW irrigation have improved their structure and porosity. Calcium and magnesium levels spiked with calcium increasing 60 folds while magnesium levels surging by more than 1000 folds. Soil sodium levels increased by an average of 70% while organic content dropped by an average of 119%. Variances between the former and latter parameters were more prominent with the Korea CC soils. Planted foliage have exhibited tolerance from the high sodium content of irrigation water. Foliage taken from the Korea CC plots generally performed better in the uptake of nutrients as compared to those harvested from P. Balagtas. Disturbingly, all harvested foliage exhibited uptake of arsenic which can be attributed to soil background contamination. Although it cannot be inferred in the experiment, potential problems associated with long-term nutrient build up may arise. Ideally, these effects can be countered by the amount of rainfall and its associated leeching. This anticipation is backed-up by the lack of sodium accumulation from 3rd soil sample taken in proximity of the WWTP final pond.*

Keywords: *reclaimed water, reuse, irrigation, sodium*

I. INTRODUCTION

CWC has long recognized the need for and the importance of sustainability to its core business. In coordination with several partners, CWC began developing environmental initiatives throughout the entire water trail. Starting with preserving valuable water resources to bringing back properly treated wastewater to rivers.

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In total alignment with its commitment to protect the environment, CWC have continuously strive in providing solutions for the scarcity of freshwater and make sustainable use of water a reality. Of particular interest to the company is to reclaim treated effluent of its WWTP. The reclaimed effluent will be used for irrigation of golf courses, park areas and food crops to trim down the water requirements of the Freeport. However, despite the potential benefits of treated wastewater irrigation as alternative water and nutrient sources for agro-systems, its land application may also cause detrimental impact as the quality limits set by Department of Agriculture (DA) for irrigation water vary to those set by the Department of Environment and Natural Resources (DENR). To further assess this situation, an investigation was carried out to test the feasibility of using the effluent as irrigation water. The objective of the study is to monitor the immediate impact of wastewater irrigation on the physico-chemical properties of soil and crop growth and nutrient uptake within the proximate vicinity of application.

A. Parameters of Significance

The locus of wastewater reclamation in the Philippines is the Department of Agriculture (DA) - setting limits on WW quality for irrigation (DA DAO26) while DENR remains the focal point for mandating policies for facilities that discharge regulated effluents in the country.

It is to be noted that DA DAO26 have imposed much stricter values for Cu, Fe, Mn and Na as compared even to the Philippine National Standards for Drinking Water (PNSDW) limits. Trace elements including heavy metals were likewise introduced to minimize undesirable effect on irrigated soils.

B. Statement of the Problem

CFZ has undergone rapid development which in turn has increased the water requirements and placed additional stress to its limited ground water supply. This development has not only increased the water demand, but also the volume of wastewater generated. The current company procedure dispose DAO35 compliant WW to a nearby creek with no diversion/recycling done. Being the sole provider of water and wastewater services, CWC is now confronted with developing sustainable plans to mitigate this dilemma and keep up with CFZ resulting growth.

One powerful mean is through the reuse and reclamation of treated wastewater for irrigating golf courses and urban landscapes. This can translate to reduced stress and demand of freshwater from our watersheds however, certain drawbacks associated with reclaimed wastewater exist.

There is limited information available locally concerning the effects of reclaimed water as irrigation for both soils and foliage. According to baseline data, Na exceed the DAO 26 standard by 21%, additional research is needed to examine and monitor the negative impacts of CWC's effluent as irrigation for its target areas. In this study, the researcher:

1. Reviewed the existing baseline environmental conditions of the Freeport and determine whether the soils are fit for reclaimed water irrigation
2. Collected firsthand data of immediate lands surrounding the WWTP's final maturation pond,
3. Examined the soil physico-chemical features of the target irrigation sites and provide technical feasibility for land application,
4. Conducted plant tissue test following irrigation of common leafy crops and ornamental grass found in CFZ golf courses and
5. Assessed the changes in soil properties after WW irrigation.

II. METHODOLOGY

The study for monitoring the effects of High Na irrigation water in target soils and foliage shall cover the following steps as highlighted in Figure 1.

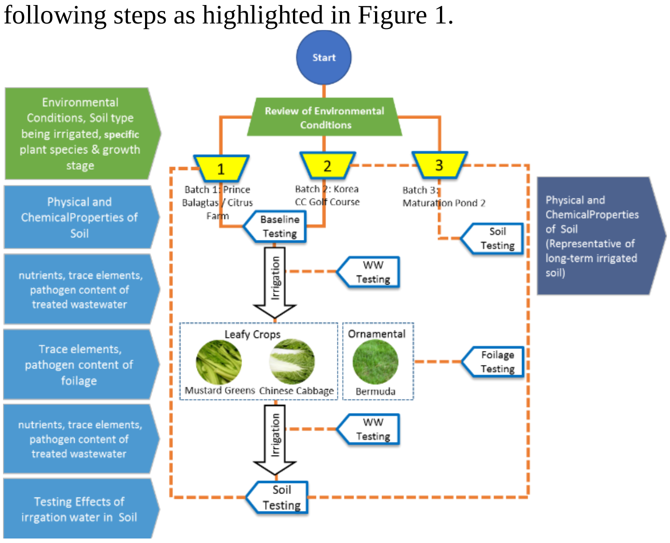

Fig. 1: Framework

Data Collection

A brief review of CWC's existing feasibility studies and environmental baseline studies was done to check upon the soil, flora and climatic conditions of the areas to be irrigated. All these are important factors since the downsides of Na arise from 1) the type soil being irrigated and 2) the specific plant species.

To test the DA prescribed soil parameters, a study will be carried out at a pilot scale using two (2) batches of triad experimental plots within the treatment plant's premises. The soils used for this experiment were collected from different sites - both inside and outside the confines of the WWTP.

1. 1st batch of soil was taken along Prince Balagtas Ave. in front of a citrus farm while
2. the 2nd batch of soil was taken from Korea CC's golf course (both are target sites for reclaimed water)

A distinct 3rd batch of soil will come from the embankment of the WWTP's Maturation Pond 2. Maturation ponds are not fortified with lining material to deflect leaching hence, a soil sample taken around the pond's vicinity may be representative of a long-time irrigated soil.

Three (3) plant species were grown from seeds in 1st and 2nd batch soils. Two (2) leafy crops; mustard greens, and Chinese cabbage and one (1) ornamental grass; bermuda. Bermuda was taken from the target market's landscape and transplanted to the experimental plots while the leafy crops were harvested during early bloom for testing.

Wastewater used for irrigation was gotten directly from the outlet of the WWTP. Each plot was irrigated daily for five (5) months with equal amounts of treated wastewater. Irrigation water will be applied by using improvised sprinklers. Application rate (approximately 1 liter of WW per day) was dependent upon the soil's capacity to absorb.

Monitoring is based according to the prescribed parameters of DAO26. CWC commissioned the services of CRL Environmental Corporation (CRL), a laboratory registered under the DENR Environmental Management Bureau (DENR-EMB) and Department of Health (DOH) to perform analysis of nutrients, trace elements and pathogen content of treated wastewater. Wastewater tests especially for SAR and EC was done on a weekly basis – while its nutrient and other trace element content was done monthly. Crops were subjected to chemical analysis while soil samples were tested for their physico-chemical properties. CRL took charge of collecting samples of sufficient volume such that the entire foliage, irrigation and irrigated land is represented.

Planting of crops and ornamental grasses was done once during the duration of the study. Each harvested foliage was subjected to testing for trace elements and pathogens. Irrigation water taken from the outlet of the WWTP were tested weekly for microbiology while its nutrient and other trace element content was done monthly. The 1st and 2nd batch of soil samples were collected before and after the duration of the study.

III. RESULTS AND DISCUSSIONS

A. Environmental Conditions

Geology

Geo-resistivity survey along the northern area of CFZ and at three barangays in Sacobia Sub-Zone stipulates that the area's topsoil consist of coarse sand mixed with gravel, coarse sand, fine sand, silty material and the clay to silt materials. The underlying materials in the project area consist mostly of unconsolidated, stratified silty sand to sandy gravel deposits. This layer cover majority of freeport's terrain and can be attributed to Mt. Pinatubo's eruption in the early 90's. Such soils, including ferrallitic soils with low activity clays and low organic matter contents have high infiltration rates and low nutrient retention capacity [1].

Climate

Based on the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), the project site experiences a climate characterized by a pronounced dry season from November to April and a wet season for the remainder of the year. Based on the long-term statistics, approximately 57% of annual precipitation occurs in July, August and September.

Terrestrial Flora

A total of 43 floral species belonging to 24 families were documented within the CFZ [2]. The most dominant growth forms are grasses and herbs and has relatively low species diversity. In general, the vegetation within CFZ consists of old growths of acacia, agoho, narra and mahogany trees. Grass species are the predominant plants thriving in vacant lots and areas, particularly those near the periphery of CFZ. Among grass species, cogon and talahib predominate.

Soil Properties

Sieve Analysis

CRL has commissioned Geotechnics Philippines, Inc. to determine the distribution of grain size of the 3 soil samples. Fig. 2 illustrates the grain size distribution of samples prior to irrigation.

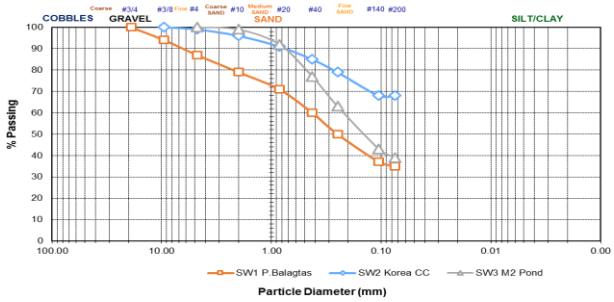

Fig. 2: Sieve analysis of the 3 soil samples prior irrigation

M2 pond (SW3) primarily consists of fine grade soils with few coarse sands. SW3's soil is comprised of 4% gravel, 11% coarse sand, 6% medium sand and 79% fine sands. Soils coming from Korea CC (SW2) exhibited almost the same physical properties as that of SW3, SW2 is composed of 1% gravel, 22% coarse sands, 14% medium sands and 63% fine sands. P.Balagtas (SW1), have higher % of large particles as compared to the former. SW1 consists of 11% gravel, 19% coarse, 10% medium sand and 60% fine sands. Samples accord with the existing baseline geology as all samples are classified as coarse grained soils with fines. These soils - being porous, have high water absorption capacity and easily drains after a heavy downpour.

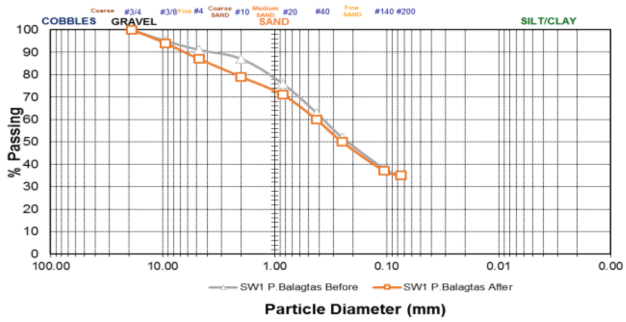

Fig. 3: Sieve analysis of P.Balagtas soil before and after irrigation

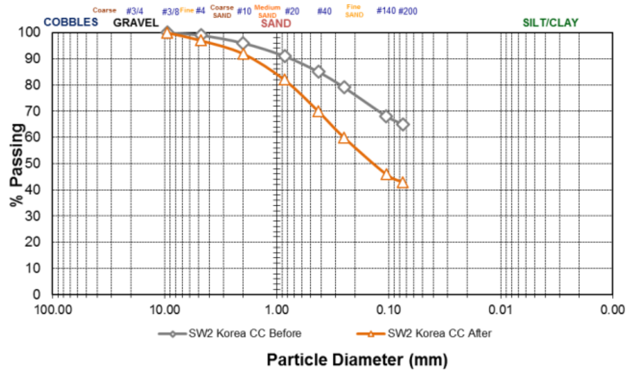

Fig. 4:Sieve Analysis of Korea CC before and after irrigation

Fig. 3 and Fig. 4 shows that irrigation by treated wastewater resulted in a slight decrease in porosity throughout the soil profile for both samples. Changes in soil porosity are more apparent for the Korea CC plot. The reduction can be attributed to the breaking of aggregates and filling of voids by nutrients and other fine particles.

Target Soil (SW1 and SW2) Properties

Nutrients

Soil samples from the Korea CC (SW2) and P. Balagtas (SW1) plots were re-analyzed following harvest. The results of analysis indicate that WW irrigation have decreased the total organic carbon (TOC) and total organic matter. The researcher contemplates that the lowering of soil organic content is affected mostly by the removal of the vegetation initially present from the soil samples. Another possible reason is the increase in earthworm population within the experimental plots. The latter's abundance is usually a good indicator of a healthy system as explained by Gupta H. 2015.[3]

Calcium, Magnesium, Sodium and Electrical Conductivity

Soil tests conducted prior the experiment classified all the soil samples as sodic type with electrical conductivities below the 4µS/cm threshold and all having sodium adsorption ratios below 13 (Bauder and Andales 2017).

Following the irrigation procedure, a significant increase in parameters were noted for the soil's calcium, magnesium, sodium, and electrical conductivity. Compared to the initial soil conditions, Korea CC's calcium levels increased more than 60 times from 0.46 meq/L prior irrigation to 28.15 meq/L after irrigation. P. Balagtas on the other hand increased 7 folds from 2.9 to 20.75 meq/L.

A favorable increase in magnesium was also observed, from an initial level of 0.17 to 190.76 meq/L for Korea CC, and 0.71 to 49.06 meq/L for P Balagtas respectively. Waging on the coarse and sandy soils present throughout CFZ, it is desirable to have slightly higher magnesium for the soils to retain more moisture.

Soil sodium levels increased slightly from 109 to 142 mg/kg for Korea C and 66 to 138mg/kg for P Balagtas after the experiment. The increase in available nutrient levels lead to the spike of the soils' EC - increasing 3 times for Korea C from an initial value of 144 to 458 µS/cm while P Balagtas conductivity increased 2 times from 126 to 276 µS/cm. In general, the nutrient surge that led to the increase in EC enhanced the soil quality since a good soil EC level is somewhere

above 200 µS/cm and 1200 µS/cm (Verma et al.2015). Fig. **5** shows the comparison of nutrients and other parameters after irrigating them for 5 months.
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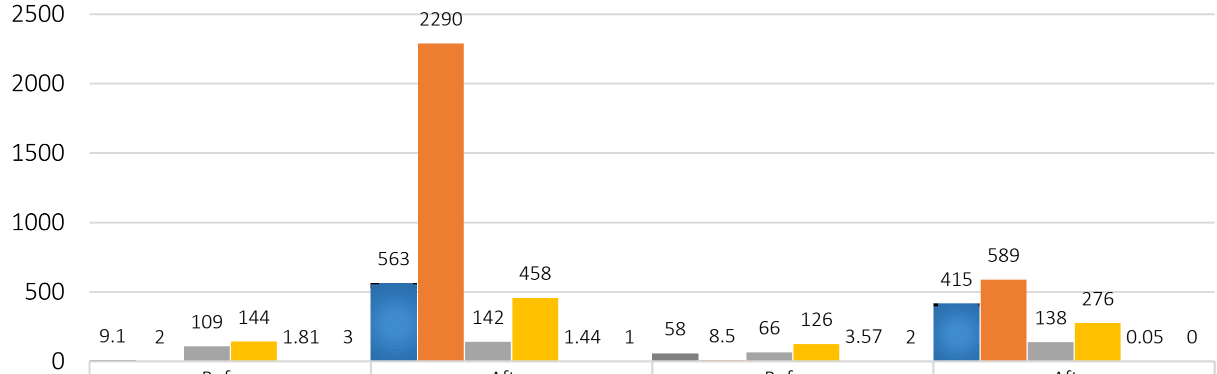
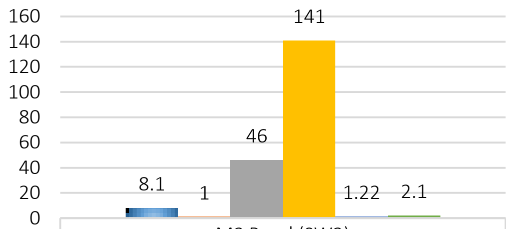


	Korea CC (SW2)		P. Balagtas (SW1)	
	Before	After	Before	After
Calcium	9.1	563	58	415
Magnesium	2	2290	8.5	589
Sodium	109	142	66	138
Conductivity	144	458	126	276
TOM	1.81	1.44	3.57	0.05
TOC	3.12	0.83	2.07	0.03

Fig. 5: Before and After comparison of soil properties

Long-Term Irrigated (SW3) Soil



	M2 Pond (SW3)
Calcium	8.1
Magnesium	1
Sodium	46
Conductivity	141
TOM	1.22
TOC	2.1

Fig. 6: Soil properties of the Long-Term Irrigated (SW3) soil

Analysis of the soil taken near the embankment of the maturation pond showed exemplary results. Despite its proximity to the final effluent, sodium levels were kept low, preceding the sodium levels of the target irrigation sites. The texture of the soils surrounding the confines of the M2 pond was found to be of fine grade sand with a bulk density of 1.06 g/mL and is composed with approximately 80% of sand. Having large particles, it is likely that the pond contents (effluent) seep through these soils. The absence of sodium accumulation suggest that the area have enough leaching of nutrients during the wet season.

B. Irrigation Water Properties

Results on the effluent analysis within the study period are shown in Figures 3 through x and are summarized in Table x. The discharged wastewater of Clark generally indicate compliance with DAO26, except for the high concentration of Na and fluctuating values of CaCO3, Fe and Mn.

Sodium (Na)

Routine testing done by CWC shows that Na levels in the effluent are quite variable. The average Na level during the initial baselining is about 1.4 times and ranges for 0.32 to 2.88 times the standard. It can also be observed that there is a slight surge on Na levels after CWC commenced its effluent disinfection using sodium hypochlorite midway 2016.

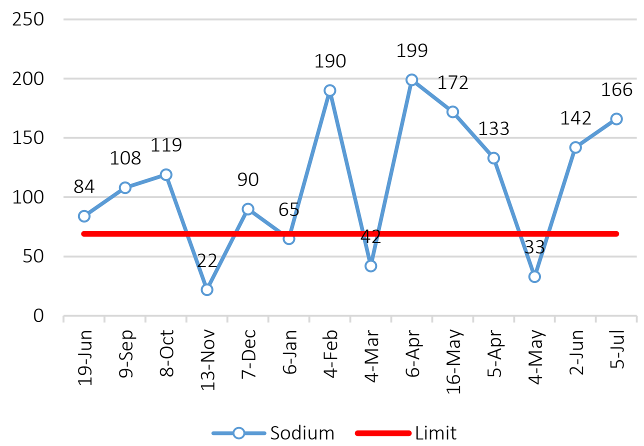


Fig. 7: Effluent Na levels from June through August

SAR and EC

It is also worth mentioning that sodium absorption ratio (SAR) which is essentially the measure of sodium hazard to soil and electrical conductivity (EC) which measure the irrigation water salinity, consistently pass the DAO 26

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standards. SAR results can be seen in Fig.8 and Fig 9 while EC in Fig.10 and Fig. 11.

SAR varies from 0.6 to 8.4 which is 3.7 up to 30 times below the permissible limits while EC on the other hand, scales at 1.19 to 2.5 below the standard. Likewise, Fe and Mg are present only in relatively small concentrations which often only marginally exceed the standards.

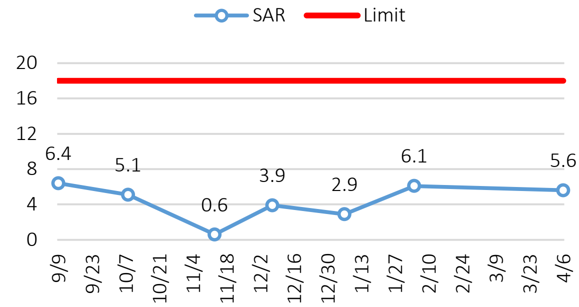


Fig. 8: Effluent SAR values from June to March

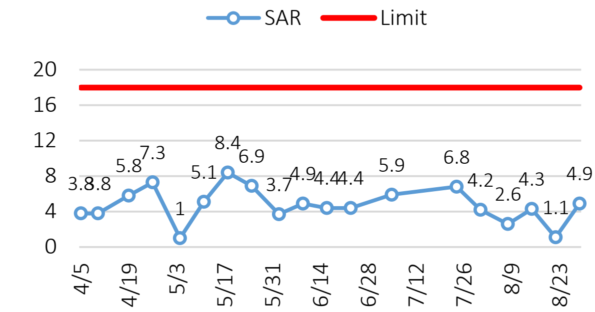


Fig. 9:Effluent SAR values from April through August

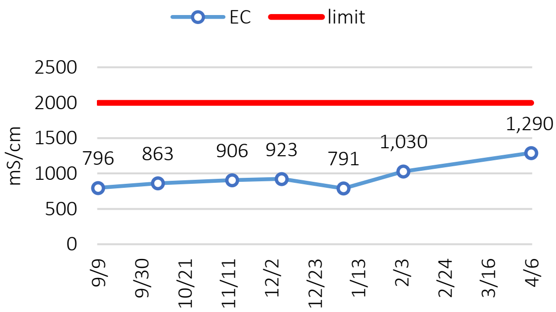


Fig. 10: Effluent EC levels from June to March

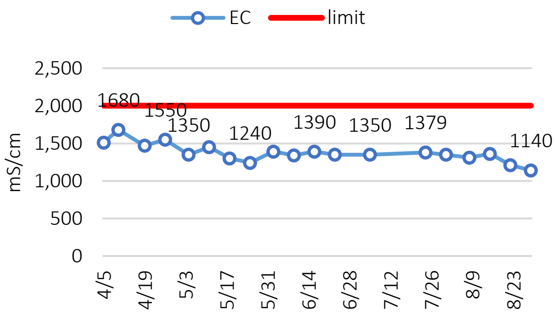
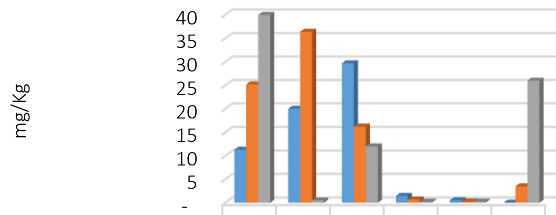


Fig. 11:Effluent EC levels from April through August

C. Foliage Properties

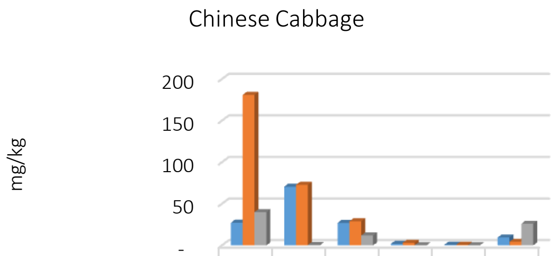
Foliage taken from the Korea CC plots generally performed better in the uptake of nutrients as compared to those harvested from P. Balagtas. Notable variances can be seen for aluminum, calcium, iron and potassium wherein the % difference of plant uptake is between 41% up to as high as 94.5%. Similarly, iron uptake has a prominent difference for the mustard greens but not for the cabbage and Bermuda grass. Substantial variation in potassium is likewise noticeable for Bermuda grass wherein the foliage uptake of the sample from P. Balagtas surpassed that of Korea C's.

Metal uptake and contamination amongst all the foliage was also recorded. Arsenic concentrations ranged from 3.3mg/kg to 14 mg/kg. These concentrations are likely to represent naturally occurring background contamination in the soils as the effluent of the centralized WWTP constantly have non-detection levels for arsenic. Greater arsenic concentrations were recorded for the cabbages. All tested foliage has non-detectable values for Be, Cd, Cr, Co, Pb, Mo, Ni, V, Hg, Li and Se.



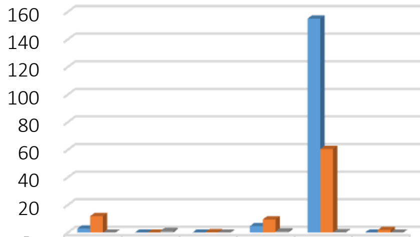
	Ca	Fe	Mg	Mn	Zn	P
Pbalagtas	11	20	30	1	1	-
Korea CC	25	36	16	1	0	4
Std. Nutrition Data	40	1	12	0	0	26

Fig. 12: Nutrient uptake of Mustard Greens



	Ca	Fe	Mg	Mn	Zn	P
Pbalagtas	27	71	27	2	1	10
Korea CC	181	73	29	3	1	4
Std. Nutrition Data	40	1	12	0	0	26

Fig. 13: Nutrient uptake of Chinese Cabbage



	Ca	Fe	Mg	Mn	Zn	P
Pbalagtas	3	-	-	5	155	-
Korea CC	12	-	0	10	61	2
Mineral Content	0	1	0	1	0	0

Fig. 14: Nutrient uptake of Bermuda Grass

IV. CONCLUSIONS AND FURTHER STUDIES

Soil samples collected from potential irrigation sites display compatibility with CWC's effluent as it has low buffering and ponding potential.

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This is in pursuant to section 10 of DAO26 wherein it states that wastewater shall only be applied if soil moisture conditions will not allow runoff or ponding in the ground surface.

Grasses found within CFZ golf courses are generally salt tolerant and can handle irrigation water with high concentrations of Na. Reclaimed wastewater had no detrimental effects on the Bermuda grass' aesthetics.

The total organic carbon and total organic matter were substantially lower after irrigation as compared to experimental plots' initial levels. The researcher could only speculate that organic levels dropped due to removal of the vegetation initially present from the soil samples and due to the profusion of earthworms that may have decomposed the remaining organic matter.

CWC's WWTP produces effluent quality that meets the required irrigation standard with the exemption of sodium which averaged 5.2 as compared to the standard of 3Meq/l during the duration of the study. This is not a significant exceedance given the intended use of irrigation water to irrigate golf courses and because the annual rainfall and the associated leeching of accumulated salts is sufficient to ensure that impacts on grass growth would not be significant. Moreover, SAR and EC are well within the acceptable limits of DAR.

Nutrient leaching throughout CFZ is expected during the wet season, this estimation is further backed up by the soil sample taken from the M2 pond which denote a long-time WW irrigated soil. The lack of sodium accumulation suggest that the area have sufficient leaching and the same can be expected of the target sites.

Effluent from the centralized WWTP continually surpass the DENR DAO35 standards with constant no-detection for Arsenic. Arsenic concentrations found on the harvested foliage can therefore be connected to soil background contamination.

Land application of treated WW considerably enhanced the soil porosity and increased soil parameters for calcium, magnesium and sodium. These higher nutrient levels translated to an increase in the soil's electrical conductivity.

Although there is significant increase in calcium levels, it is outdone by the percentage increase in magnesium. A certain problem that may present itself in the future is having too much magnesium in the soil as it hurts drainage, porosity and ultimately lower yield of crops. The best solution is to ensure soil drainage to leach excess nutrients during rainfall.

Based on the findings, it can be inferred that soils and foliage of the target sites are capable of handling CWC's effluent. However, considering the accumulation of nutrients over the short-term experiment, continuous long term monitoring of target site's soil phy-chem and base saturation changes preferably during dry season (when wastewater irrigation is at full blast) and after the wet season (to verify leaching of excess nutrients) is of major importance. It is therefore recommended that a longer observation period be conducted as well as increase the sample size. Another thing to improve is the use of placebo group for negative control.

There is currently insufficient soil test information available to confirm the source of arsenic contamination. Further soil investigation within the target sites is recommended to better point the source that led to the detection of arsenic within the plants. Until verified, it is wise to restrict the use of reclaimed water for food crops.

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Manalang Mark Franklin P. A registered Master Plumber, Registered Mechanical Engineer and a Registered Environmental Impact Assessment (EIA) Preparer. He is currently an Operations Manager for Clark Water Corporation (CWC). Mark also teach for the Mechanical Engineering Department of Holy Angel University (HAU) where he handles fluid mechanics, fluid machineries, engineering ethics, and logistics management. He is also a freelance - with a Research & Design background, focused on water quality and wastewater designs of individual clients up to municipal level treatment plants. Mark also has several research publications to his credit in several international journals. He finished both degrees for BS Mechanical Engineering and Master's in Engineering Management at HAU and is now completing his PhD in Nueva Ecija University of Science and Technology (NEUST).

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Dizon Prolan D. is a registered Electronics Engineer and a licensed professional teacher. He is currently working as a college instructor for engineering students in one of the state universities in the Philippines. He worked as a manufacturing engineer in one of the electronics companies in the country and abroad which gave him a profound skills and experiences in his field. He also worked as a Senior Trainer in one of the business outsourcing companies in the country providing customer service and technical assistance to customers for a Telco account based in the United States. Being part of the training team plus an added inspiration from his mother who is a public teacher, he decided to be part of the academe. In line with his goal to professional development, he continued his studies in Nueva Ecija University of Science and Technology (NEUST) taking up Master's in Engineering Management.

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