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THE APPLICATION OF WATER FOOTPRINT AND SIX-SIGMA METHOD TO REDUCE THE WATER CONSUMPTION IN AN ORGANIZATION

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ABSTRACT: The water footprint is the virtual amount of water use related to different activities. Currently, the water scarcity and untreated water are the critical issues that many organizations have to deal with. In this study, the water consumption activities of a public organization are studied and assessed within the context of water footprints. Basically, the consumption in the target organization is categorized into three categories, domestic use, agricultural use and indirect use due to transportation and electricity. The study is not only limited to the blue and green but also grey water footprint as well. In order to efficiently tackle the problem, the six sigma method (DMAIC) was utilized as a guideline to reduce the water footprint systematically. Pareto diagram, types of footprints (blue, green and grey) and a feasibility study were utilized to select the critical sources of water consumption. There are two sources of water consumption identified as the primary target to improve. One is the polluted water caused by the fertilizer used in the experimental farm and another is the indirect water use regarding the fuel consumption of the vehicle fleet. The cause and effect diagram was applied to determine the potential cause which leads to the minimization of water consumption in both categories, water/green and grey water footprint. After the feasibility study was conducted, the results indicate that the fuel consumption in the University vehicle fleet is a potential target that the appropriate measure should be implemented. Another target is the polluted water caused by fertilizer use in the demonstration farm. Afterward, the improvement and control measures were recommended to the organization executives for a further implementation leading to reduce the water consumption and to maintain sustainability. Therefore, the amount of water consumption should be effectively reduced by integrating the method of water footprint and six-sigma.

Keywords: DMAIC, Organization, Six Sigma, Water footprint.

1. INTRODUCTION

Water is an important resource for every aspect of a human's life. However, one of the emerging problems is the scarcity of water in many areas of the world so water conservation is the important key to solve this problem. Although most people realize the importance of water saving, the dilemma is still that they do not take it seriously. The results of many studies show that most people do not tend to understand the whole picture of how much water is consumed on each daily activity. As a result, if the water consumption of each product or process is numerically calculated so it can be used as the consumption indicator like a price tag. Therefore, people know exactly the impact of their activities on the environment, especially, water. According to the study, the amount of water usage in the public sector is also considered high so it is important to implement an efficient method to reduce water consumption.

In this research, the primary target is the assessment of water consumption in the organization and the pilot study was conducted on a public University. The reason is that most activities of the organization always require a large amount of water. According to the Metropolitan Waterworks Authority of Thailand, the large-sized organization can consume up to 129,979,000 liters per year. After the assessment, the causes of major water consumption were identified, the improvement method was applied to the current activities with the objective to reduce water consumption in the organization.

2. LITERATURE REVIEW

According to the literature, the method of the water footprint is utilized as the tool for the assessment of water consumption regarding a variety of activities during the whole life cycle of a product or service. The method of the water footprint is also applied in different areas, e.g., agriculture, manufacturing, and domestic use. For the water consumption in the agricultural sector, a study by [1] indicates that the production of rice in many Asian countries relies on more green water than the blue one. Moreover, the exported rice to 27 European Union (EU) countries is responsible for the grey or polluted water accounted for approximately 8 percent of the total water consumption. According to Hoekstra and Mekonnen [2], the global water footprint heavily

depends on agricultural production which contributes to 92 percent of the whole water footprint. Totally, the amount of water footprint due to the different types of footprints, i.e, green, blue, and grey, which are 68, 13, and 19 percent respectively.

The water footprint does not only relate to the direct but also indirect consumption. A number of studies were also conducted to determine the relationship between water consumption and energy generation.

Scown, Horvath and McKone [3] show that energy consumption in the transportation system has a great impact on water consumption since there is a fundamental connection between energy and water. Elina and Esther [4] have assessed the amount of water used to produce the biofuel in Spain which is widely consumed in the transportation section. The replacement of fossil fuel by the renewable one (biodiesel and bio-ethanol) was studied by [5] and the result signifies that it involves the significant amount of water consumption. Moreover, the study also reveals that the production of biodiesel needs more water than the bio-ethanol. The global water footprint assessment for the electricity generation was carried out by [6] and the study points out that water is the essential source for heat and electricity production. Moreover, the current amount of water consumption in this category increases significantly in previous years.

Due to a number of studies, water footprint is a power indicating tool for the assessment of water consumption. However, the reduction of consumption will be possible only if it is implemented integrally with the appropriate improvement method, e.g., six sigma. For the success story in the industries, Sadraoui, Afef, and Fayza [7] have utilized six sigma technique to reduce and optimize the water consumption at Coca-Cola Company. Furthermore, Kaushik and Khanduja [8] reported that water consumption in the thermal power plant was significantly reduced after the implementation of the six sigma method. Franchetti, Bedal, Ulloa, and Grodek [9] show that the integrated technique of lean six sigma and green is a potential tool to increase the efficient utilization of water in the industry. Parveen, Kumar, and Rao [10] also applied the integrated method of the lean and green supply chain in the manufacturing firms to reduce water usage. The study of the impact of the lean and agile method on the reduction of water footprint in the construction industry was conducted by [11]. Therefore, the literature indicates that there are many reports regarding the potential integration of the water consumption indicator and the six sigma method. However, this study has extended the implementation of these integrated methods for the reduction of water consumption in the organization. Moreover, the appropriate measures of improvement will be determined and recommended to the executives.

3. SCENARIO

Therefore, if the organization can effectively identify the activities which cause a large amount of water consumption, it will lead to a significant reduction of water usage in the organization. In this research, the pilot study was conducted on a public University in Thailand, Valaya Alongkorn Rajabhat University, whose activities involve a number of consumption activities. The University offers both undergraduate and graduates degrees to part-time and full-time students and it is operated daily from Monday to Sunday except the national holidays. It is the medium-sized University. There are about 10,000 students and 700 University personnel. The University campus is shown in Fig. 1.

Fig. 1 University campus

The assessment was carried out since there are many activities that are related to water consumption. This includes the transportation for official use, electricity use, agricultural use in the experimental farm, domestic water consumption, and polluted water. After the assessment, the initiatives following the six sigma method were conducted and applied to the current process with the purpose of reducing water consumption.

4. RESEARCH PROCEDURES & RESULTS

The research procedures follow the steps of six sigma method and they are differentiated into five stages, i.e., define, measure, analyze, improve and control (DMAIC) as follows:

4.1 Define

At this stage, the problem statement of the research should be clearly defined. Obviously, there is an attempt to reduce the amount of direct and indirect water usage in the organization. Therefore,

the research problem focuses on the effort to minimize water consumption related activities. These activities can be categorized into indirect water usage (water used in the production of fuel and electricity), domestic use and polluted water. The time span of the study covers the period of 8 months from January to September 2018.

4.2 Measure

The method of water footprint was utilized in order to assess and measure the amount of virtual water related to all activities which lead to water consumption. The water footprint of all activities is measured in the unit of a liter.

The indirect consumption is based on two main activities, electricity use and fuel consumption of the vehicle fleet. However, Another category is the direct consumption which is caused by domestic water usage, agricultural use, and polluted water.

4.2.1 Electricity

The electricity consumption and water footprint were calculated for the period of four months in [14]. However, in this study, the electricity use was measured from January to September 2018 and the water footprint was calculated. The measurement is done through meter readings at each building in the University. The total number is 20 buildings and the main source of electric consumption is the air conditioning system as shown in Fig. 2.

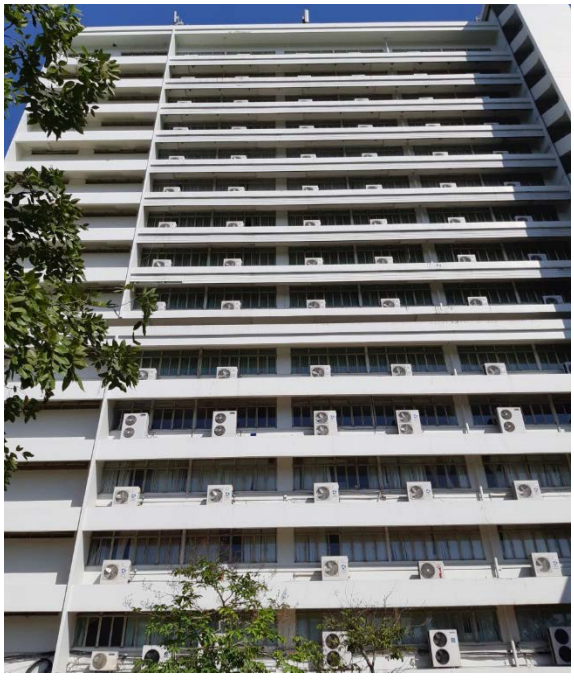

Fig. 2 Air conditioning units in a building

The unit of electricity measurement is kWh (kilowatt-hour) and the life cycle analysis of water consumption on the electricity generation is 0.26 liter/MWh. As a result, the total amount of water consumption according to the electricity is shown in Table 1.

Table 1 Electricity use and their water footprints

Building	kWh	Liters
Canteen	79,600	20.70
Science Education Lecture Hall	68,000	17.68
Office of Learning Promotion and Provision Academic Services	162,636	42.29
Language and Computer Center	144,399	37.54
Demonstration School	230,254	59.87
Green House	6,171	1.60
Plant Genetics Preservation	10,016	2.60
Student Affairs Division	7,360	1.91
Faculty of Science and Technology (Office and lecture hall/rooms)	157,360	40.91
Faculty of Science and Technology (Home economics lecture rooms/laboratory)	15,810	4.11
Faculty of Humanities and Social Science (Office and lecture hall/rooms)	97,600	25.38
Faculty of Humanities and Social Science (Student government office)	63,240	16.44
Faculty of Industrial Technology	219,436	57.05
Faculty of Agriculture Technology (Office and lecture rooms)	28,960	7.53
Faculty of Agriculture Technology (Laboratories)	235,440	61.21
Faculty of Education 1	94,680	24.62
Faculty of Management Science 1	270,260	70.27
Total		491.72

4.2.2 Transport

The University vehicle fleet consists of 2 buses, 20 vans, 4 pick-up trucks and one light truck (6 wheels). Some vehicles are shown in Fig. 3.

Fig. 3 Vehicle fleet

The type of fuels they consume are both gasoline and diesel. These fleets are daily assigned to provide transportation for the official use of the University personnel and students. The fuel consumption due to the transportation activities from January to September 2018 was measured and calculated as shown in Table 2.

Table 2 Fuel consumption and their water footprints

Fuel	Water Footprint (water gallon/ fuel gallon)	Fuel used (liter)	Water footprint (Liter)
Gasoline	5.8	12,000	69,600
Diesel (biodiesel)	2.8	1,000	2,800
Total			72,400

The detailed study in Table 2 shows that gasoline use contributes to the highest water consumption (69,600 liters). Therefore, the best pathway leading to water reduction is to decrease the use of gasoline.

4.2.3 Agricultural use

Since University has an experimental farm which is used to grow paddy rice (Fig. 4). The rice yield of the crop is approximately 500 kg. The water supplies of the rice field are from two sources, i.e., rainwater and irrigation water. According to a study by [12], in the Chao-praya river region, the rice yield of 1 kg requires the amount of rainwater and irrigation water for 1.08 liter and 0.35 liter respectively.

Fig. 4 Paddy rice field

According to the study by [14], the approximate amount of water consumed to produce a batch of rice in the season is 540 liters for green water footprint and 175 liters for blue water footprint. The total water footprint is 715 liters.

4.2.4 Domestic Use

Since the mission of the University is to provide education services to students, the routine daily activities regarding water use include cleaning, washing, toilet use, gardening, and other domestic uses. Since the approximate amount of water usage per person is 100 liters/person/day, the total number of students and University personnel are 1,500. Therefore, the water consumption for nine months is roughly 40,500,000 liters. Another source of domestic use is for a gardening purpose which is about 1.7 liters/m^2/day. Since the green area of the University is about 20 rais or 32,000 m^2, The amount of water used for 9 months is equal to 7,344,000 liters.

4.2.6 Greywater

The source of greywater is typically from the toilet use, dishwashing (mainly from University cafeteria), and showers (residential halls). Normally, the greywater in the University is drained into a pond (Fig. 5) and barely undergoes the treatment which includes the oxygenation. Therefore, it is quite impossible to reuse it for other purposes, e.g., plant watering.

Fig. 5 Untreated water in a pond

4.3 Analyze

The analysis tools, i.e., Pareto diagram and cause and effect diagram, were used to analyze the significant source of water usage. The amount of water consumption for domestic and gardening purposes are exempted from the analysis even they account for the highest portion of water use. The reason is that it deals with the actual need for the consumption and it requires the cooperation from the public for the habit change. The mindset change is gradually slow and takes time. Therefore, only the remaining sources are taken into consideration. To start the analysis, Pareto diagram was used to identify the source which contributed to the highest amount of water consumption. Another influential factor to be considered is the type of water footprints.

For the blue and green water footprint, according to the Pareto chart in Fig. 6, the main source of the water footprint is the fuel consumption for the transportation which holds the highest percentage of water consumption (88 percent) followed by

electricity, domestic use and others. Therefore, it is interesting to note that the first priority to reduce water consumption should focus on the reduction of fuel consumption in the University vehicle fleet. For the grey water footprint, the source of polluted water to be minimized in the sewage caused by fertilizer.

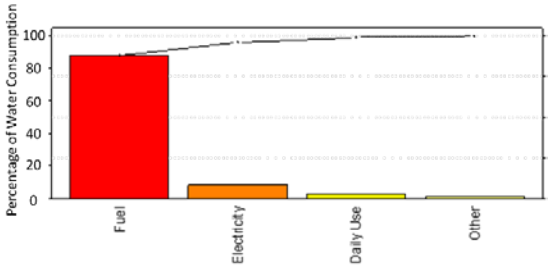

Fig. 6 Pareto chart

After the utilization of Pareto, the further analysis was conducted to determine the causes leading to the reduction of water footprints, i.e., blue and green water footprint and polluted water, i.e., grey water footprint. The tool used is the cause and effect or fishbone diagram.

4.3.1 Blue and green water footprint

The improve stage activities are divided into two categories. The first is to assess the amount of water consumption regarding two major processes in the organization, transportation and electricity use. The second is the application of six sigma method to reduce water consumption. The major gasoline consumption is from the University vehicle fleet which is for official use. Therefore, the only solution is to reduce consumption. As a result, the cause and effect or Ishikawa diagram are utilized to analyze the causes of the effect, i.e., gasoline use reduction. Different experts are interviewed and brainstormed, a potential list of the causes is depicted in the form of cause and effect diagram as shown in the following Fig. 7.

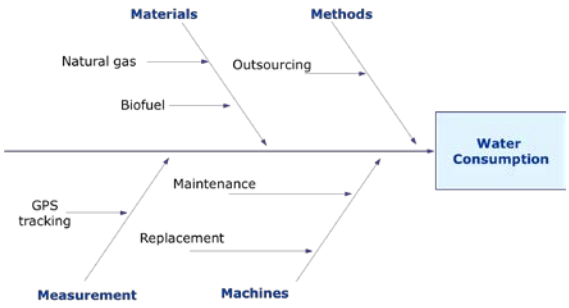

Fig. 7 Cause and effect diagram (blue and green water footprint)

According to Fig. 7, different categories of causes are listed based on four main genres, i.e., materials, methods, machines, and measurements.

-Materials: For materials, the commonly used fuel in the vehicle fleet is gasoline. As a result, the different type of fuel with less consumption of water, e.g., natural gas, should be used instead of gasoline.

However, the engine system needs an upgrade so the economic analysis must be assessed. Moreover, since the vehicle engine is originally designed for the gasoline used, the natural gas might affect the tribology of the engine. The engine might need more frequent service in the long run.

-Machines: In this case, the machine is the engine itself. To increase the fuel-saving rate, the regular maintenance might help to increase the engine performance. Therefore, this will lead to the significant saving of the fuel.

-Measurements: Since Bangkok is the capital of Thailand and her traffic is among the worst in the world, the fuel consumption is contributed to the traffic. Moreover, it also has the complex road network so it is easy to get lost. As a result, the solution to this problem relies on technology. Currently, the GPS tracking system mostly come up with smartphones and Google map is the powerful software which will help to find the fastest route to the destination. As a result, if all drivers use the GPS and its software, it will reduce the time spent in the traffic significantly.

-Methods: To reduce the official use of the fleet, the alternative solution turns to the outsourced service. Although the transportation activities will switch from the University's vehicle fleet.

4.3.2 Grey water footprint

For grey water footprint, the analysis by the cause and effect diagram in Fig.8.

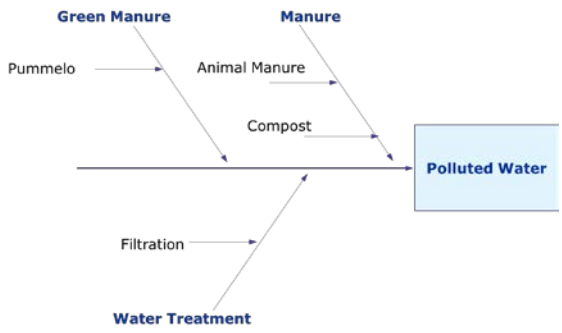

Fig. 8 Cause and effect diagram (grey water footprint)

The result in Fig. 8 regarding the fertilizer use can be concluded in Table 3 as follows:

Table 3 Causes of the grey water footprint

Cause	Assessment
Green manure	It is recommended that the fertilizer can be replaced by Pummelo.
Manure	Not only green manure but also manure (animal manure or compost) can be used.
Water treatment	The filtration system is required in order to treat the polluted water.

4.4 Improve

After the analysis stage, the most important phase of the research is the introduction of different measures to improve the current situation (minimize water consumption). Based on the study, two improvement measures are recommended to the executives in the organization. These measures are based on the type of water footprint.

4.4.1 Blue and green water footprint

After all the options are identified, the experts have brainstormed together and scored the potential option to practice. The results show that the utilization of GPS might be the best option to practice. Because of the advanced technology, GPS and its navigation software are commonly equipped in most smartphones. Therefore, most drivers have access to an efficient and robust navigation system. The sample of the navigation through the Google map is shown in Fig. 9.

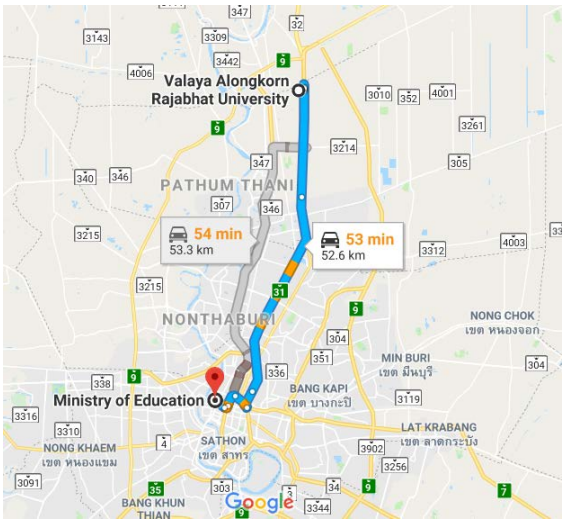

Fig. 9 Navigation system

According to Fig. 9, the example shows that there are two routes, A = 53 min, 52.6 km and B = 54 min, 53.3 km (Table 4), so the driver can correctly choose the most optimal route.

Table 4 Route and distance

Route	Distance/time
A	53 min, 52.6 km
B	54 min, 53.3 km

4.4.2 Grey water footprint

The polluted water in the organization comes from different sources. One of the most significant sources is the polluted water due to the agricultural sector since there is the application of chemical fertilizer in the field which causes the water footprint. The fertilizer use is known to heavily pollute the water and the consequence is the increasing amount of grey water footprint. An alternative to fertilizer, green manure, is recommended to be used in order to reduce the grey water footprint. During the post-harvest season, Pummelo, a kind of cover crops, is suggested to be grown and plowed in the paddy rice field. Since the plant itself is rich with Nitrogen, if Pummelo is grown in the area of 1 rai (0.16 hectare), it will be equivalent to the formula 46-0-0 fertilizer for 15 kg. The consequence will be the reduction of fertilizer use for approximately 49,600 liters. Pummelo is shown in Fig. 10.

Fig. 10 Pummelo

4.5 Control

After all the steps were carried out, the remaining step is as important as the previous ones. The control stage will ensure that all the implemented measures are sustainable. For the sustainability of water consumption for the transportation sector, the logbook should be equipped in every vehicle (in the driver seat pocket) and drivers may be asked to fill out the form before starting the journey. The solution to the problem is practice to ensure that the cause of the problem is solved. The measurement has been done in order to validate the results. For the

minimization of grey water footprint, the Pummelo growing should be scheduled right after the harvest of paddy rice in every season. It is important to introduce it as the cycle to farmers between growing paddy rice and Pummelo.

5. CONCLUSIONS AND DISCUSSIONS

In conclusion, this research objective is the reduction of water consumption due to the activities in the organization. The method of six sigma was utilized as a guideline leading to the minimization. At the measure (M) stage, the amount of virtual water or water footprint was measured and calculated. The analyze (A) stage was carried out to rank and prioritize the sources of water consumption based on the amount and feasibility. At this stage, the most critical source was also pointed out and selected as the target. Not only the source of blue and green water but also grey water footprint was analyzed and the in-depth analysis was conducted on two consumption sources, polluted water from the experimental farm and the indirect consumption of the transportation fuel consumption. Afterward, different measures were determined and recommended for further implementation in the organization. The amount of reduced consumption was projected in the improvement (I) stage. At the last stage (control), the initiatives were introduced and recommended to ensure that the results of the improvement will be sustainable in the long run. The application of the last two stages (improvement and control) will be possible only if there is committed cooperation from the top executives of the organization.

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