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Identifying High Influence Parameters using Genetic Algorithm (GA) Chromosomes for Water Consumption

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Abstract: Severe uncertainties climate changes course flood and droughts disaster have made clean water precious for domestic consumption. Thus, securing clean water is important. Wastage of water comes from water consumption such as from household usage. However, monitoring water consumption from household usage is tedious and time consuming. This work utilized Genetic Algorithm (GA) to optimize the coefficient of micro-components of water consumption (CMWC) values to determine high influential household routine parameters. Nine household parameters have been investigated namely, bath/shower, personal hygiene, flush toilet, wash cloth by hand, wash cloth by washing machine, food preparation, water plant, washing car and miscellaneous. These parameters are encoded as a chromosome data in GA to incorporate the CMWC values. The aim is to minimize the residential water consumption estimation error rates and subsequently enabling increased accuracy towards estimating and classifying the amount of residential water consumption. Data average monthly water consumption were collected from 80 households in Seremban. Water consumption has been categorized into three groups of low (L-PDWC), medium (M-PDWC) and high (H-PDWC). Comparison was made between per capita water consumption (PCC) and Domestic Water Consumption via Genetic Algorithm (DWC-GA) error rate's values. The results are as follows; PCC method's error rates of 9.49 and DWC-GA error rate is 1.05.

Keywords: Genetic Algorithm, water consumption household routines

1. Introduction

Clean water is precious. Droughts, major flood, earthquakes are disaster that could lead to clean water shortage. One way to save water is by monitoring the monthly household water consumption to avoid water wastage. Water wastage could be caused by carelessness, water hoarding during water rationing, pipe bursting and leakages [1]. Irregularity in monthly domestic water consumption can be detected based on its average.

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Thus, monitoring domestic water consumption is important nowadays. It is important to monitor monthly household water consumption to avoid water wastage. By identifying which household routines contribute largely to the water consumption, people are aware of their consumption and can manage the routine efficiently and wisely. The high-water bill also is an important factor for consumers to be aware. Knowing the characteristic of household water consumption can help citizen to save money. Domestic water consumption is affected by various factors such as number of households, type of house and occupation [1-3]. Moreover, depending on the type of technology used such as water-using appliances and fixtures associated, consumption for a specific household routine can differ greatly [4-6]. However, in Malaysia, there is a limited study on water consumption patterns by different household routines [6]. Therefore, there is a need to acknowledge that household routine also plays a major role in affecting household water consumption as it is accumulated directly from the household routines. Furthermore, by recognizing the household water consumption by household routines will help to a more practical and current demand estimations of the domestic sector. Thus, it is vital to understand the drivers of water consumption at a household level and how consumption can be reduced while maintaining wellbeing.

Household routine involving water-using appliances includes indoor and outdoor water consumption. According to Keshavarzi [7], indoor water consumption consists of hygiene, drinking as well as cooking, whereas outdoor consumption comprises of car washing, livestock watering and yard cleaning.

Past research has categorized household water consumption into daily and weekly. Daily routines include bath and shower, personal hygiene, and flush toilet [8-10]. On the other hand, household routines done in weekly basis comprises of laundry, food preparation, water plant, wash car and other miscellaneous routines [11-14]. Household water consumption is difficult to estimate. Generating a value that allow each household's water consumption estimation is beneficial.

This research therefore proposes the optimization of coefficient of micro-component of water consumption (CMWC) for the household routine parameters. The optimized CMWC values can be utilized to provide satisfactory estimation and classification for monthly household water consumption. The proposed algorithm can help raise awareness among household consumers on the water conservation particularly on the high-influenced household routines. For example, by identifying which household routines contribute largely to the water consumption, they are aware of their consumption and can manage the routine efficiently and wisely. In addition, household consumers can estimate their monthly household water consumption if there are any changes to their typical routines or household size. They can also acknowledge their usage to non-excessive, normal, or excessive. Moreover, the proposed algorithm can be adapted and utilized to produce a more reliable and accurate estimation and classification for household consumers. Hence, it will enable the household consumers to estimate the level of water supply consumption that they are currently utilizing and manage the consumption wisely.

Apart from the household consumers, the proposed algorithm will also benefit water supply companies in developing initial adaption strategies to implement the use of water efficient appliances installed at residential household. In addition, the accurate estimation and classification of water consumption will also allow water supply companies to be able to decide the level of adequacy for water supplies for different areas such as urban and rural areas. Besides that, the proposed algorithm will enable the water authorities to deliver the appropriate supply of water conveniently in case of climate changes or forecast uncertainty.

2. Review of the Literature

Research that investigates on how to determine domestic water consumption are many [14-16]. For instance, Inocencio et al. [4] in their studies determined basic household water requirements through a record keeping approach and use of an econometric tool. The research obtained actual per capita water consumption by activity based on household water usage and determines household and per capita water requirement that cuts across income classes, water sources and cost of water, and location. Results of this study provide a valuable input in water-sector planning, allocation of available water supply between domestic and other uses and in determining the appropriate water tariff consumption block and structure for domestic consumption. Furthermore, this research gives and empirical basis for the lifeline or minimum consumption block of about 10m^3 per month for a family of 6 members. The concern for determining basic minimum water requirement for a person is significant as the growing scarcity against a rapidly rising population. It is noted that no study has, so far, objectively estimated basic water requirement by household activity such as drinking, personal hygiene, among others, for Malaysia.

Equations on how to calculate residential water consumption are many [3][6][17-18].Those equations involve total water use for shower, total water use for hand wash, total water use for teeth brushing, total water use for flushing, total water use for dishwashing, total water use for cloth washing, total water use for garden. To calculate the actual water consumption, the equation involves maximum rate of daily water consumption times no. of people in the house [3].

Currently, the government in Malaysia uses domestic water consumption based on per capita water consumption (PCC) from National Water Services Commission (NWSC) [19] to assist in determining water management strategies. According to Florida Department of Environmental Protection [20], PCC is the average amount of water each person in a particular area consumes daily. As stated by Reed and Reed [21], a person needs about 70 L of water daily to maintain a life. In Malaysia, the PCC for different state differs from one to another.

There are different PCC values for every state in Malaysia [19]. States with higher density of population such as Pulau Pinang recorded a higher number of PCC compared to state with lower density of population such as Kelantan. However, these values are basically an average number that is calculated based on the water consumption recorded from the previous year hence is ineffective for accurate estimation due to the variation of factors and different conditions [15-16][22-24]. Moreover, one-year difference is a large gap to estimate the current water consumption. Thus, calculation of the PCC used as a measure to predict water consumption are debatable.

• Domestic Water Consumption

Human demand for water is predictable to increase as the world population is also predicted to grow to 8.5 billion in 2020 and 9.7 billion in 2050 [25]. As in mid-2015, sixty percent of the global population (4.4 billion) people lives in Asia. Haddeland [26] states that irrigation water scarcity is particularly large in parts of southern and eastern Asia and is expected to become even larger in the future. Water consumption in Malaysia is disturbingly high and increasing every year [27]. Currently, some regions in Malaysia are facing water scarcity problem although Malaysia has high quantity of water resources [28]. As stated by Phang et al. [29], most of domestic water consumer in Malaysia does not practice water saving thus it will lead to water shortages in the future if the Malaysian still practicing the same attitude. Water consumption varies greatly from one region to the other as well as from one household to the other due to several factors such as different climate, socio-economic and demographic characteristics of each region [30].

• Parameters Influencing Domestic Water Consumption

This work categorized the parameters that influence domestic water into nine types. There are bath and shower, personal hygiene, flush toilet, laundry by handwashing, laundry by washing machine, food preparation, water plant, wash car and miscellaneous.

Bath and Shower

Practically, daily household routines in the home bathroom consumes the most water in the household. Thus, bath and shower account most of the residential water consumption [5][17]. In India, bathing consumes the highest amount of water consumption [3] which accounts for about 55 percent of residential water consumption [31]. In Malta, it was found that showering makes up 34 percent (80.4 L per person per day) of residential water consumption [30]. Besides that, Willis et al.[32] agreed that the highest end use of residential water is showering (50 L per person per day) equating to 33 percent of total consumption. Furthermore, Bari et al. [6] also identified that showering is the highest residential water consumption in Malaysia which amounted to 124.8 L per person per day, almost as double to the estimation of 78 L per person per day calculated for Thailand households. In [8] studies, the authors had found from the 1,188 data logged homes, bath and shower make up 18.5 percent of indoor residential water consumption.

Personal Hygiene

In this research, personal hygiene routines comprised from brushing teeth, washing hand and face. The water consumption for personal hygiene routines is varied as researchers and water companies have different findings for this routine. For instance, NYC Environmental Protection indicated that brushing teeth with the water running consumed about 4 gallons (15.14 L) of water, contrast to Haida et al. [17], brushing teeth with running water consumed only 1.7 L. In addition, Khalid et al [22] revealed that brushing teeth used a minimum amount of 8 l/p/d to a maximum amount of 40 l/p/d. Furthermore, in some of the findings, the consumption for brushing teeth and washing hand or washing hand and face are combined as these practices are usually done one after another. According to Howard and Bartram[10], the most critical times of washing hand are following defecation and before eating. Mostafavi et al. [11] suggested that rinsing with 2 L of clean water proved to be protective although this seems to consume a large amount of water.

Flush Toilet

One of the household routines involving water-using appliances is flushing toilets. Mayer et al.[33] studied and found that toilet flushing was the largest component which accounted for 26.7 percent of indoor per capita water use. Water consumption for this activity also differ depending on the types of toilet and the frequency of toilet flushing in a day. There is a considerable amount of literature on the toilet flushing models [4]. For instance, old toilets can use up to three times more water than current required fixtures. According to Household Guide to Water Efficiency [13], older toilets probably used between 13 L to 20 L of water whereas new toilets consume only 6 L or less. The study also found that single-flush toilets flush the same volume of water every time the flush handle is activated. While for dual-flush toilet models, a larger volume of water to flush solid waste or a smaller volume of water to flush liquid waste.

Laundry by Handwashing

Laundry routines can be done using handwashing and washing machine. Laundry by handwashing is the least favorable as it is both time and energy consuming. Also, there is not many studies focused on this routine compared to other household routines in this research. However, few researchers discussed the consumption of laundry by handwashing in their studies. As estimated by [4], the basic requirement for laundry by handwashing is 4.7 L per wash. Meanwhile, Dutch households used about 1.7 L per wash, only one percentage of the overall PCC [33]

Laundry by Washing Machine

Laundry by washing machine were the second largest component of indoor consumption [8]. Water consumption for laundry varies depending on the technology used, types of washing machines (e.g., semi-automatic, fully-automatic, and front or top load) and number of volumes per load [4]. In terms of types of washing machines, there are also significant difference in the amount of water consumption between front and top loaders. Front loader washing machines are more water efficient as it requires less water per cycle. Several researchers and water authorities identified the average volumes of water used per cycle for front loaders were 78.5 L [14], 60 L [61], 71 L [62] and 15 L to 113 L [34] per cycle. It has also been found that the top loader washing machines consumed 153 L [14],150 L [61] ,143 L [62] and 151 L per cycle [34]. Besides that, older washing machine models also consumed a large amount of water. Haida et al. [17] found that younger washing machine used 44 L per cycle whereas older washing machine consumed 100L per cycle.

Food Preparation

Food preparation is a household routine involving cooking and drinking on a weekly basis. The water consumption for this activity varies depending on the household size and the frequency. Typically, family with a large member prefer to cook at home rather than eating outside due to cost. Moreover, defining the requirements for water for cooking is difficult, as this depends on the diet and the role of water in food preparation [10]. According to Household Guide to Water Efficiency [13], kitchen water consumption accounts for about 15 percent of total indoor water use. While drinking and cooking has the lowest water consumption for Indian residential households, cooking and bathing consumes highest amount of water in New Town [3][9]. In addition, considering drinking needs, Howard and Bartram [10] suggested between 1.5 and 2 l/p/d is used for drinking. In the literature, the average of water consumption for food preparation were mostly between 4 l/p/d to 10 l/p/d [33][35]. To summarize, although the water consumption for food preparation is relatively low, it is difficult to be determined since many factors such as different types of foods and number of servings also needs to be considered.

Water Plant

Water plant is one of the outdoor household routines in the study. There are a few options to water the plants such as using pail, hose or water pipe, watering can and sprinklers. Water consumption differs based on the fixtures and tools used. Gato et al. [14] analyzed households that used hose and manual sprinklers consumed the highest amount of water per garden watering (488 L) due to its long duration (59.1 min) although they only water their garden less than twice per week (1.8 times). Using Water at Home (2017) also stated that hand-held hose or sprinkler consumes 18 L per minute of water compared to a bucket or watering can that used about 9 L per bucket. The study conducted by [14] also found that 57 percent of households used hose as their main method of garden watering, followed by manual sprinklers (23 percent) and automatic sprinklers and combination of hose and manual sprinklers (20 percent). Furthermore, [6] discovered that outdoor uses such as gardening consume minimal water consumption. Greech[30] also presented Maltese households used only two percent (5.1 l/p/d) whereas [3] reported only six percent of water consumption of overall domestic water consumption were used to water plants. To sum up, how the households watering their plants need to be noted as there is a big difference using a bucket and sprinkles in the garden.

Wash Car

Washing cars is an outdoor household routine that either contribute to a small or large water consumption depending on the number of own cars and various ways of washing it. Depending on the device used, trigger nozzle hose consumed 18 L per minute while high pressure cleaning device consumed 6 L per minute. In addition, households that have reported using hoses to wash cars do not have particularly higher outdoor use [11]. According to Greech[30] car washing only make up a small component of water consumption (5.1 l/p/d). Ramulongo et al. [3] studied and showed that the households used about 13.5 l/p/d to wash cars. Meanwhile, in Europe some countries restrict the water consumption to 60-70 L per car. Moreover, in a recent paper by Haida et al. [17], it has been found that the amount of water for washing a car was 100 L. Average Water Use [36] otherwise suggested 200 L was the amount needed to wash a car. In conclusion, cars also vary in terms of size hence the water consumption may differ greatly depending on the car model.

Miscellaneous

Outdoor household routines comprised of unknown leakage and cleaning (e.g. drains and pavement wash) is considered under miscellaneous routines. Exceptionally high leakage figures are typically found in houses with swimming pools, outdoor water features, hot tubs and irrigation systems [8]. The literature on miscellaneous routines shows a variety of consumption. Several publications indicated that water used for this routine did not exceed more than 50 l/p/d. For instance, the estimated consumption in the low range included 1.4 l/p/d, 3.1 l/p/d (Inocencio et al., 1999), 3.8 l/p/d and 5 l/p/d [22]. Furthermore, several authors also proposed the average amount of between 10 to 15 l/p/d used for miscellaneous routines [33]. In the analysis done by other researchers, slightly higher of water was used for this routines such as 28 l/p/d [35], 31.7 l/p/d [37] and 36 l/p/d [30]. Although the authors did not precisely state the breakdown of water usage for the miscellaneous, most of the authors agreed that miscellaneous activities were categorized under outdoor household routines.

• Optimization Algorithm

Solving optimization problems require efficient algorithm as straightforward approach. Consequently, there are various optimization algorithm that can be employed for optimization problem. Commonly, optimization problems are usually tackled by employing efficient algorithm such as evolutionary optimization algorithms [38].

Evolutionary optimization algorithms are stochastic nature-inspired algorithms that aims to optimize a problem by continuously evolving its candidate solution to the point where the solution can no longer be improved or converged. Examples of evolutionary optimization algorithm includes genetic algorithm (GA), particle swarm optimization (PSO), ant colony optimization (ACO), cuckoo search, bat algorithm, and firefly algorithm [38].

The basis of evolutionary optimization algorithm involves the process of problem representation. In this case, GA for example represents the candidate solution of a problem via chromosomes [39]. Subsequently, algorithms PSO represents the candidate solution as particles [40], and ACO represents as ants respectively [41]. These candidate solutions will then go through different stages of operation to continuously improve the candidate solution to finally find the optimal solution or global optima. The stages of operation for each algorithm differs to one another, with each algorithm names characterizes the overall operation of respective algorithms. For example, firefly algorithm characterizes the attractiveness of the firefly according to the brightness intensity [42].

To date, the algorithm that is commonly employed for regarding water consumption is GA where it is shown to be efficiently used for optimal pump operation for water distribution [43], optimizing minimum freshwater consumption for single contaminant water-using systems [44] and optimizing water usage and treatment network [45]. However, there are only few research regarding the employment of evolutionary optimization algorithm that to directly estimates and classify household water consumption.

• Overview of Genetic Algorithm

Genetic algorithm arguably is an optimization algorithm that popularize the nature-inspired optimization methods [46]. This algorithm took Darwin's process of natural selection to optimize a given problem [39]. In GA, the candidate solutions in a population will undergo the process of evolution in which the fitter candidates will thrive in the population while the lesser will not survive and subsequently eliminated from the population. Genetic algorithm (GA) is one of the most popular algorithms that can be employed to tackle various optimization problems [30] and until recently can still be seen utilized to optimize various optimization problems [47-50].

The basic process of GA includes five different phases namely the chromosome (problem) encoding, population initialization, fitness evaluation, crossover and mutation, and convergence [51]. Problems in GA are usually encoded in the form of binary and values such as floating points [52]. The sequence of the chromosomes will represent the candidate solution in each problem. The number of chromosomes (candidate solutions) in a population also plays a significant role in GA. GA will be initialized with a fixed number of initial populations that represent the preliminary solution towards the overall process. Increasing the number of chromosomes in turn will allow more variations towards finding the optimal solution [53]. Theoretically, small number of chromosomes will allow faster convergence for the GA. Despite that, the solution may be trapped in local optima which means there exist a better solution, but the algorithm does not manage to find the global optimum due to the fact that there are not enough variations in the population [54]. In this research however, the number of chromosomes is bounded to the amount of household data in the dataset as the GA will attempt to optimize the parameters among all household.

Every contending chromosome in GA will compete with one another to preserve its existence. This is where the concept of "survival of the fittest" applied in GA. The fitter chromosome will have a greater chance to survive while the lesser will eventually remove [55]. The fitness of the contending candidate solutions is evaluated by a fitness function that is linked to the intended problem. A fitness function can be anything, if its main function is to find the quality of the candidate solutions. The fitness of the chromosome will be in terms of minimizing the cumulative errors that are generated by all households.

Crossover and mutation are basically the most important phase that defines GA. This phase is what allows GA to create diversity within the population to gratify the solution space. Crossover and mutation allow better solution to be obtained by exchanging building blocks between individuals in the population [56]. After the completion of the selection phase, the traits of the selected chromosomes are separated and recombined with one another by crossover operation.

The offspring generated from crossover will be carried to the next generation for further evaluation. Mutation is a secondary operation after crossover operation is performed to further increase the diversity of candidate solutions in a population [57]. This operation is executed with a fixed rate for the generated offspring. The mutation process adjusts some part the inherited traits into other new criteria that does not belong to the parent chromosomes which will further increase the diversity of the candidate solutions [58]. In this research, crossover and mutation are employed to avoid the algorithm trapped in local optima by increasing the diversity of the candidate solutions.

Convergence is the final phase in GA which checks whether the algorithm can be stopped. Subsequently, GA will continue its execution by repeating the previously discussed phases until a stopping criterion is finally met [59]. There are different types of stopping criterion that can stop the execution of the algorithm. If the optimal solution is known a-priori, the algorithm will be stopped once it reaches the specified result. The algorithm can also be stopped if a common solution is continually generated after the end of each generation. Lastly, this algorithm may also be stopped once it reaches a specified number of generations specified by the user [60].

In this research, there are several specified numbers of generations that will be tested to allow the algorithm to produce optimal solution towards the problem.

3. Methodology

This work consists of three major steps: data collection, algorithm design and implementation and experimental design of establishing PDWC values of the work.

3.1 Data Collection

Data collection consists of a secondary data collected by a group of students (Bachelor of Science (Hons) Statistics) in Universiti Teknologi Mara (UiTM) Seremban. This data has been used in the study by Rasmani et al[15] to detect excessive residential water consumption and to predict domestic water leakage based on consumer water consumption data. The data was collected using a questionnaire survey carried out randomly in an urban area in Seremban to 80 households with a total of 367 occupants. There was no specific residential area stated in the data sets. The type of residential households in this sample consists of single store terrace and double store terrace. In addition, the age of the residential households is between one year old to 44 years old. Among 80 households, there are 27 households with children and 53 households without children. For this research, the household routines involving water-using appliances have been selected as the primary parameter to estimate the household monthly water consumption using GA. Table 1 shows the household routines as a parameter and identifier used.

3.2 Algorithm Design and Implementation

In this phase, the algorithm to optimize coefficient of micro-component water consumption (CMWC) values is designed and constructed. This section starts with the basic structure of Genetic Algorithm (GA). As illustrated in Fig. 1, there are six stages to this algorithm that consists of chromosome encoding, chromosome population, chromosome selection, crossover, mutation, and convergence.

3.3 Chromosome Encoding

The first step in DWC-GA is chromosome encoding. Chromosome encoding is basically the step in which the current problem is encoded. The encoding technique used in this research is object encoding which represents genes in terms of object. As illustrated in the Fig. 2, each chromosome is encoded with a unique house identification (e.g. H0001), household size (number of households), frequency of household routine parameters, CMWC values, average monthly household water consumption (12-month period), estimated monthly household water consumption and fitness (error rate) value. As stated in Table 1, there are nine household routine parameters in each chromosome. The household routine parameters are divided into daily (p_1 - p_3) and weekly (p_4 - p_9) routines. Each parameter has its own CMWC values which are generated as random floating-point numbers between 0 and 1. These random numbers are generated via .NET Framework API which took account of the current system time as the seed to produce generated numbers. The CMWC values represents how influential the parameters towards the water consumption where 0 presents low influence and 1 presents high influence.

3.4 Chromosome Population

The chromosome population is the number of chromosomes in each generation. In this step, chromosome will be randomly created, combining varieties of different parameters. This is done to produce more variations towards the algorithm. In this research, the population size is 80 which is the total number of households from the sample survey.

Fig.3 shows that there are 80 different combinations of parameters that can be evaluated. The number of generations is set to 1000.

Table 1 - Parameter (Household Routine) and identifier

Household Routines (Survey)	Parameter	Identifier
Bath/Shower	Bath/Shower	p_1
Brushing Teeth/ Washing Hands/Face	Personal Hygiene	p_2
Flushing Toilet	Flush Toilet	p_3
Washing Clothes by Hand	Laundry – Handwashing (per load)	p_4
Washing Clothes by Washing Machine	Laundry – Washing Machine (per load)	p_5
Cooking	Food Preparation	p_6
Watering Plant	Water Plant	p_7
Wash Car	Wash Car	p_8
Other	Miscellaneous	p_9

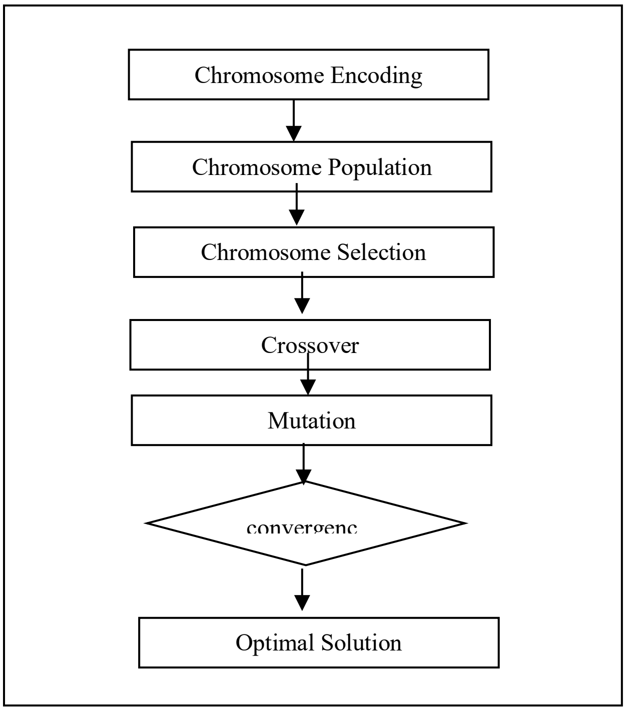

Fig. 1 - Stages in domestic water consumption via Genetic Algorithm (DWC-GA)

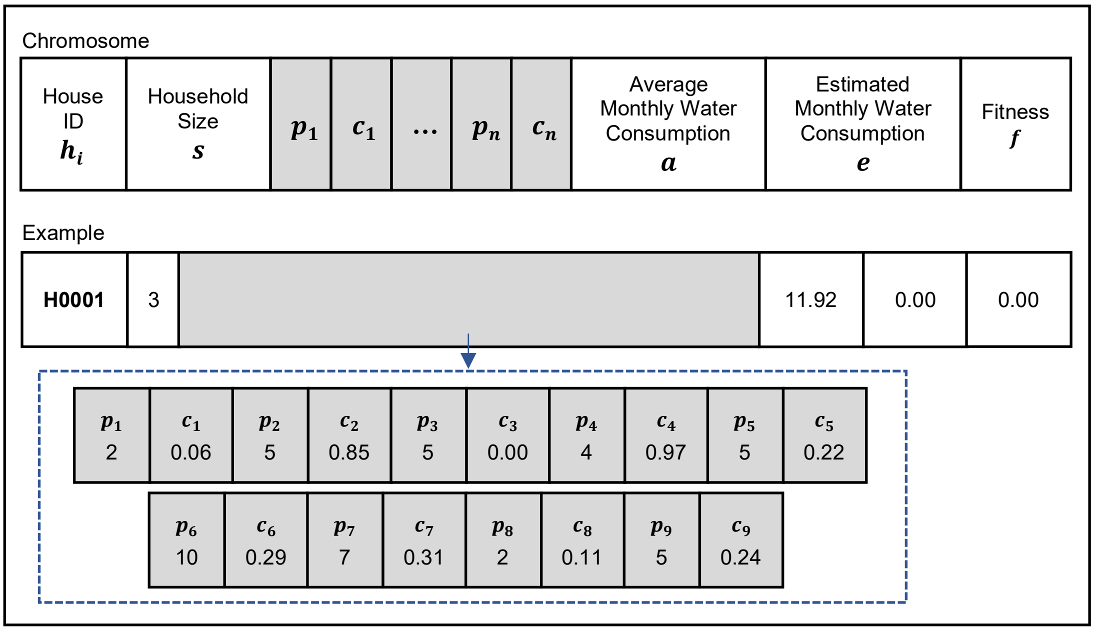

Fig. 2 - Chromosome encoding

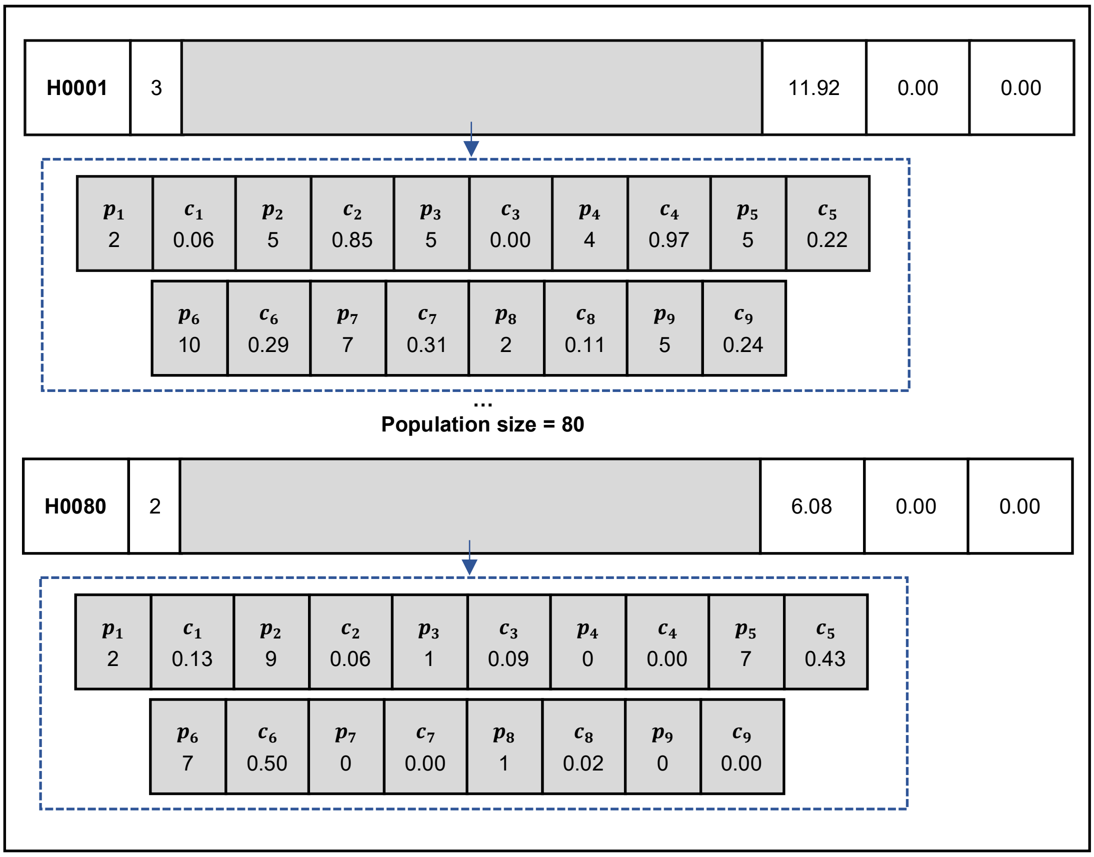

Fig. 3 - Chromosome population

3.5 Chromosome Selection

This research used rank selection to sort the fitness values from low to high. To get the fitness values, the chromosome must estimate the monthly household water consumption. To estimated monthly household water consumption, Equation 1 is employed.

$$\boldsymbol{e = d + w} \tag{1}$$

$$\boldsymbol{d = \sum_{n=1}^{3} (sp_n a_n)(30)(c_n)} \tag{2}$$

$$\boldsymbol{w = \sum_{n=4}^{9} (p_n a_n)(\frac{30}{7})(c_n)} \tag{3}$$

The estimated monthly household water consumption (e) is the addition of daily (d) (Equation 2) and weekly (w) (Equation 3) consumption. Based on the Equation in 2 and 3.3, n refers to household routines parameters identifiers. s is household size, p_n is frequency of household routine parameters, a_n is pre-determined water consumption values, c_n is coefficient of micro-component water consumption (CMWC) values.

Each chromosome fitness values are evaluated using Equation 4 where f is fitness (error rate) value, e is estimated monthly water consumption and a is average monthly household water consumption. The objective function essentially minimizes the f where better and fitter chromosome has lower error rate while inferior chromosome has higher error rate.

$$\boldsymbol{f = e - a} \tag{4}$$

The number of population size is fixed to 80 (total number of households) and is executed with 1000 generations. The number of generations is set to 1000 to accommodate three different volumes of PDWC values (L-PDWC, M-PDWC, H-PDWC). If the number of generations are more than 1000, the results show no significant changes thus 1000 generations would suffice. The objective function of DWC-GA is the minimized error rates of the estimated water consumption values. Additionally, single-point crossover is selected to double the rate of variation by splitting the parent chromosomes into half. Also, the high number of mutation rate (50 percent) is intentional to produce more variations towards the current solution to avoid the algorithm to be trapped in local optimum. Besides that, the experiment is executed 100 times due to the constraint of small population size in this research. During each experiment, the optimized CMWC values and total error rates of 80 households for every generation is recorded. Subsequently, the best optimized CMWC values corresponding to the lowest error rates are selected for each household by averaging the CMWC values from the 100 executions.

3.6 Experimental Design of Establishing PDWC Values

The household's characteristic data obtained from the survey served as bases to provide guideline in GA. There are nine household routines parameters involved in this experiment which includes bath and shower, flush toilet, personal hygiene, laundry by handwashing, laundry by washing machine, food preparation, water plant, wash car and other miscellaneous routines. Each household routine parameters will have three different volumes of Pre-Determined Water Consumption (PDWC) which designates low (L-PDWC), medium (M-PDWC) and high (H-PDWC) consumption. The volumes of PDWC are deduced by using the PCC of Malaysia and Seremban, and the study from Bari et al. [6] on the water consumption for different household activities as the guideline.

In this research, PDWC values are one of the most vital parameters in estimating the monthly household water consumption efficiently. However, defining an amount of water consumption for a household routine is strenuous due to numerous factors such as different models of water fixtures and appliances. This experiment is done to establish satisfactory amount of water consumption intended for the nine household routine parameters. A summary of experimental design for this experiment is represented in Table 2.

Each household routine parameters will have three different volumes of PDWC which designates low (L-PDWC), medium (M-PDWC) and high (H-PDWC) consumption. The volumes of PDWC are deduced by using the PCC of Malaysia and Seremban, and the study from Bari et al. [6] on the water consumption for different household activities as the guideline.

The purpose of DWC-GA is to optimize CMWC values in addition to minimize the error rates. In this section, a detailed account on the experimental design of DWC-GA is presented. Table 3 depicts parameters, constant value and method involved in DWC-GA.

Table 2 - Establishing PDWC values and verifying high-influenced household routine parameter

Parameters	Constant Value/Method
Household Routine Parameters	Bath and Shower Flush Toilet Personal Hygiene Laundry by Handwashing Laundry by Washing Machine Food Preparation Water Plant Wash Car Miscellaneous
PDWC Volumes	Low (L-PDWC) Medium (M-PDWC) High (H-PDWC)
Per Capita Consumption (PCC)	211 L/p/d (Malaysia) 223 L/p/d (Seremban, Negeri Sembilan)
Point of Reference	Bari et al. [6]
Optimized CMWC Values	0.00 – 1.00

Table 3 - Experimental design of executing DWC-GA

Parameters	Constant Value/Method
Chromosome Encoding	Object Encoding
Population Size	80
Generation	1000
Objective Function	Minimized Error Rates (Fitness Values)
Crossover	Single-point
Mutation	Randomly, 50 percent
Number of Execution	100

In the initial stage of the process, the chromosome is encoded using object encoding where the genes are represented in terms of objects. The number of population size is fixed to 80 (total number of households) and is executed with 1000 generations. The number of generations is set to 1000 to accommodate three different volumes of PDWC values (L-PDWC, M-PDWC, H-PDWC). If the number of generations are more than 1000, the results show no significant changes thus 1000 generations would suffice. The objective function of DWC-GA is the minimized error rates of the estimated water consumption values. Additionally, single-point crossover is selected to double the rate of variation by splitting the parent chromosomes into half. Also, the high number of mutation rate (50 percent) is intentional to produce more variations towards the current solution to avoid the algorithm to be trapped in local optimum. Besides that, the experiment is executed 100 times due to the constraint of small population size in this research. During each experiment, the optimized CMWC values and total error rates of 80 households for every generation is recorded. Subsequently, the best optimized CMWC values corresponding to the lowest error rates are selected for each household by averaging the CMWC values from the 100 executions.

Table 2 describe the experimental design to verify the high-influenced household routine parameters. Each household has their own optimized CMWC values of household routine parameters for three different PDWC values. The optimized CMWC values defined power. This gives the formal solution to be found as high optimized CMWC values has more influences on the monthly water consumption and vice versa. The experiment is done by averaging the optimized CMWC values for 80 households.

4. Result and Discussion

All The household routines parameters comprise of bath and shower, personal hygiene, flush toilet, laundry by handwashing, laundry by washing machine, food preparation, water plants, wash car and miscellaneous routines. Each household routines parameters have its own water consumption values more specifically groups into three volumes of water consumption: low (L-PDWC), medium (M-PDWC) and high (H-PDWC). As in Table 4, L-PDWC is the minimum and basic requirement of the water consumption of the household routines whereas M-PDWC is the average and common consumption and H-PDWC is the most likely high of water consumption.

Table 4 - Parameter (Household routine involving water-using appliances) and pre-determined water consumption values

Parameter (Household Routines)	Identifier	L-PDWC	M-PDWC	H-PDWC
Bath/Shower	p_1	45	90	180
Personal Hygiene	p_2	4	12	20
Flush Toilet	p_3	10	30	60
Laundry by Handwashing – per load	p_4	5	10	15
Laundry by Washing Machine – per load	p_5	20	50	150
Food Preparation	p_6	4	10	15
Water Plant	p_7	5	20	30
Wash Car	p_8	20	100	200
Miscellaneous	p_9	10	30	50

The performance of the proposed DWC-GA is evaluated by minimizing and reducing the fitness error to the smallest possible values appropriately and compatible within the range of its own PDWC. As by doing so will result in better estimation of the household monthly water consumption. Once the fitness error for each generation is optimized for the subsequent generation, the proposed DWC-GA is considered has reach convergence and it is regarded as optimal solution. To validate the algorithm, the convergence of the proposed DWC-GA is examined by analyzing the relation between generation and fitness (error rate). The convergence testing for each volume of pre-determined water consumption values is demonstrated in the following section.

Each PDWC values are run for 100 times since this study has a small number of populations. The execution is done many times to further the exploration on the diversity of the CMWC values for each household. The graph in Fig. 4 outlines the relation between generation and fitness (error rate) for L-PDWC, M-PDWC and H-PDWC. From the graph, it is apparent while the generation increased, the fitness (error rate) decreased for each volume of PDWC. The fitness (error rate) started to drop significantly around 20th generation before remained relatively stable between 200th and 300th generation. The fitness (error rate) is consistently constant until 1000th generation. As illustrated in the graph, fitness (error rate) for L-PDWC is high compared to M-PDWC and H-PDWC. In addition, both M-PDWC and H-PDWC have almost similar trend in terms of fitness (error rate) and generation. Overall, it is possible to conclude that each volume of PDWC has succeed in minimizing the fitness (error rate) and reached convergence.

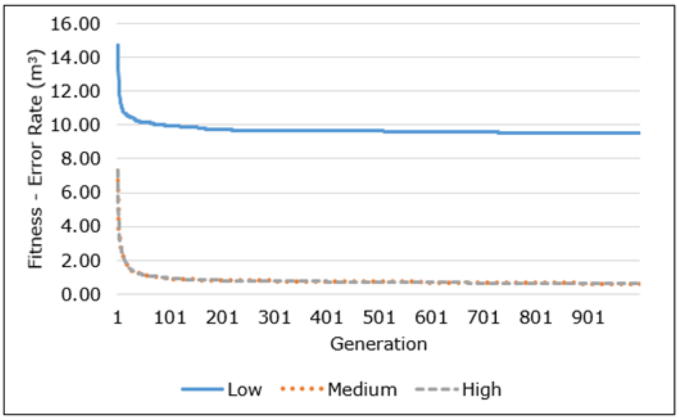

Fig. 4 - Fitness (Error Rate) versus Generation Graph for L-PDWC, M-PDWC and H-PDWC

These nine household routine parameters and PDWC values helps to rule out other external factors affecting the domestic water consumption. Each parameter's CMWC value is optimized and the result from the optimization is congregated to discuss which parameters have higher influence (in terms of individual CMWC value) than others. Fig. 5 depicts the mean of the optimized CMWC values of L-PDWC, M-PDWC and H-PDWC for 80 households. It shows that P1, P2, P3, P5 and P6 are the most influential parameters for L-PDWC and M-PDWC while P9 recorded the lowest average CMWC for all three PDWC. Fig. 6 shows the trends for nine household routine parameters based on the

CMWC values obtained from DWC-GA. The CMWC values for P1, P2 and P3 are slightly distant from one another compared to P5-P9 specifically when complemented with H-PDWC and M-PDWC. In Fig. 7, it is shown that the error rate of the DWC-GA when complemented with the low pre-determined water consumption value returned the worst error rate (802.74) even when being compared with the average PCC water consumption estimation. This is largely due to the pre-determined water consumption value defined for the "low" water consumption is too small and returned a high error rate even when complemented with the CMWC value.

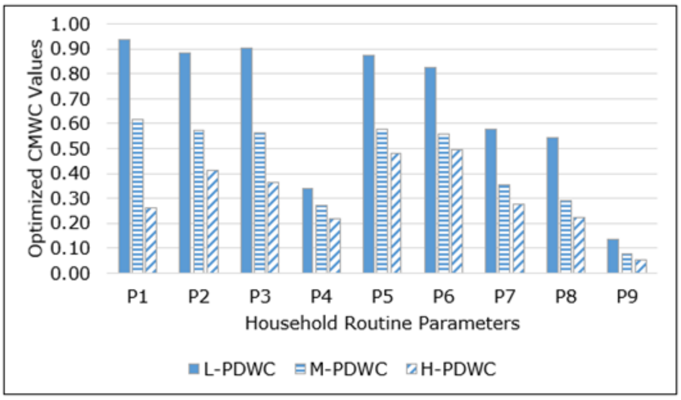

Fig. 5 - Low, Medium, High, and Average CMWC Values for Each Household

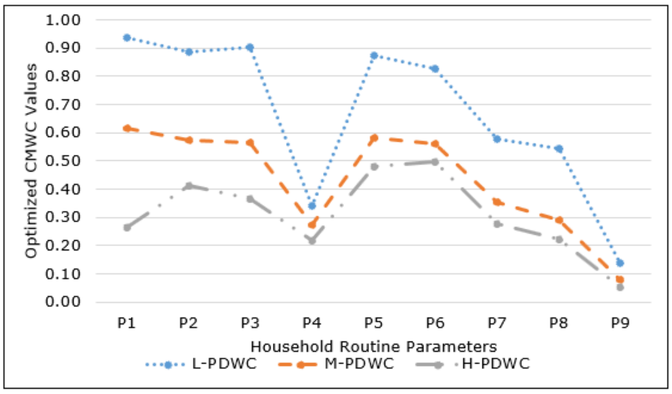

Fig.6 - Trends for Low, Medium, and High Average CMWC Values for Each Household

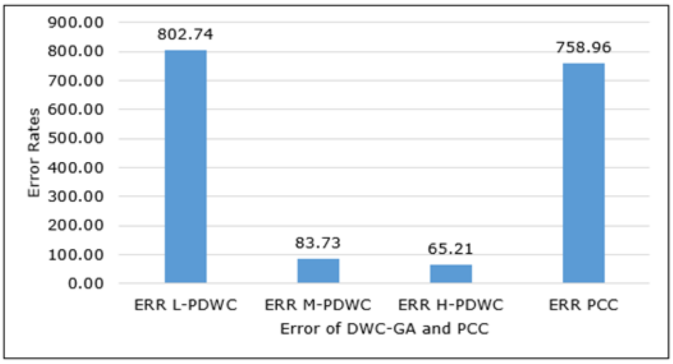

Fig.7 - DWC-GA and PCC Error Rate of Low, Medium, High and PCC

Table 5 - Mean Error Rates of Estimating 80 Household's Water Consumption

Methods	Error Rates (m^3)			
	DWC-GA (L)	***DWC-GA (M)***	***DWC-GA (H)***	***PCC***
Mean Error Rates	10.03	1.05	0.82	9.49

Table 5 shows the mean error rates comparisons between DWC-GA and PCC. The result shows that PCC (9.49) has greater mean error rate compared to DWC-CA (M) (1.05) and DWC-GA(H) (0.82). As for DWC-GA(L) has 10.03 value.

Overall, the findings revealed that bath and shower, personal hygiene, flush toilet, laundry by washing machine and food preparation are the most influential household routine parameters. In addition, from the findings, it can be concluded that outdoor household routines have the least influential household routines.

5. Conclusion

This study successfully determined nine household routines parameters involving water-using appliances that influenced household's water consumption. Genetic algorithm (GA), term as DWC-GA, has been used to optimized Coefficient of Micro-components of Water Consumption (CMWC) thus able to determine the characteristic of water consumption of household routines. Comparison was made between PCC (conventional method) and DWC-GA. Results show that DWC-GA able to produce better mean error rate.

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References

[1] Luciani, C., Casellato, F., Alvisi, S., & Franchini, M.(2019). Green Smart Technology for Water (GST4Water): Water Loss Identification at User Level by Using Smart Metering Systems. Water,11, 1-14

[2] Lu, L., Deller, D., & Hviid, M. (2019). Price and Behavioural Signals to Encourage Household Water Conservation: Implications for the UK, Water Resources Management. 33:475-491

[3] Ramulongo, L., Nethengwe. N.S., & Musyoki, A. (2017). The nature of urban household water demand and consumption in Makhado Local Municipality: A case study of Makhado Newtown. Procedia Environmental Sciences, 37, 182-194

[4] Inocencio, A.B., Padilla, J.E., & Javier,E.P.(1999). Determination of basic household water requirements. Philippine Institute for Development Studies. 1-60

[5] Hani, N.N., Rasmani, K.A., Khalid, N.E., & Fadzil, A.F.A. (2019). Determining influential household routines for domestic water consumption estimation via Genetic Algorithm. Proceedings of the Third International Conference on Computing, Mathematics and Statistics (iCMS2017), Springer, Singapore, 3-9

[6] Bari, M.A., Begum, R.A., Nesadurai, N., & Pereira, J.J. (2015). Water consumption patterns in greater Kuala Lumpur: potential for reduction. Journal of Water; Environment and Pollution. 12(3), 1-7

[7] Keshavarzi, A., Sharifzadeh, M., Kamgar Haghighi, A.A., Amin, S., Keshtkar, S., & Bamdad, A. (2006). Rural domestic water consumption behavior: a case study in Ramjerd Area. Fars Province, I.R. Iran. Water Research, 1173-1178

[8] Mayer, P.W., DeOreo, W.B., Opitz, E.M., Kiefer, J.C., Davis, W.Y., Dziegielewski, B., & Nelson, J.O. (2016). Residential end uses of water, AWWA Research Foundation and American Water Works Association

[9] Shaban, A., & Sharma, R. (2007). Water consumption patterns in domestic households in major cities, Economic and Political Weekly. 2190-2197

[10] Howard, G., & Bartram, J. (2003). Domestic water quantity, service level and health. World Health Organizations.

[11] Mostafavi, N., Shojaei, H., Behestian, A., & Hoque, S. (2018). Residential water consumption modeling in the integrated urban metabolism analysis tool (IUMAT). Resources Conservation and Recycling, 131, 64-74

[12] Shan, Y., Yang, L., Perren, K., & Zhang,Y. (2015). Household water consumption: insight from a survey in Greece and Poland. Procedia Engineering. 1409-1418

[13] CMHC.S. (2014). Household Guide to Water Efficiency. Canada Mortgage and Housing Corporation, 1-40

[14] Gato-Trinidad, S., Jayasuriya, N., & Roberts, P. (2011). Understand urban residential end uses of water. Water Science Technology, 64(1), 36-42

[15] Rasmani, K.A., Hanif, H.M., & Ramli, N.M. (2014). Detecting excessive residential water consumption using statistical process control and machine learning approaches. WIT Transactions on Information and Communication Technologies, 187-193

[16] City of Morror Bay.(2015).How to calculate your average daily per person water usage. Retrieved from https://www.morrobay.ca.us/DocumentCenter/View/8428/How-to-Calculate-Avg DailyUse?bidId=

[17] Haida, C., Chapagain, A.K., Rauch, W., Riede, M., & Schneider,K. (2018). From water footprint to climate change adaption: capacity development with teenagers to save water. Land Use Policy, 80, 456-463

[18] Hoekstra, A.Y., & Chapagain, A.K. (2005). The water footprint calculators: water footprint network. Retrieved from http://www.waterfootprint.org/?page=cal/WaterFootprintCalculator

[19] National Water Services Commission. (2017). Domestic Water Consumption. Retrieved from National Water Services Commission

[20] Annual Report. (2014). Florida Department of Environmental Protection. Retrieved from https://floridadep.gov/files/2014-annual-reportpdf
[21] Reed. B, & Reed, B. (2013). How Much Water is Needed in Emergencies. Technical Notes on Drinking Water, Sanitation and Hygiene in Emergencies, World Health Organization, 1-4.
[22] Khalid, N.E., Hani, N.N., Rasmani, K.A., Fadzil, A.F.A, & Ibrahim, S. (2019). Pre-Determined Household Routines Parameters Values of Domestic Water Consumption. International Journal of Advanced Trends in Computer Science and Engineering. 8. 424-430
[23] Hassan, F.A. (2013). Analysis of Domestic Water Consumption in Malaysia, Thesis,Master of Engineering (Civil - Hydraulics & Hydrology),Universiti Teknologi Malaysia
[24] Memon, F.A & Butler, D. (2006). Water Consumption Trends and Demand Forecasting Techniques. Water Demand Management, 1-26
[25] United Nations. (2015). World Population Prospects: The 2015 Revision, Key Findings and Advance Tables. Department of Economic and Social Affairs, Population Division
[26] Haddeland, I.H. (2014). Global Water Resources Affected by Human Interventions and Climate Change. Proceedings of the National Academy of Sciences, 111(9), 3251-3256
[27] Sung, C.T.B. (2011). Water Consumption and Crop Water use in Malaysia, Retrieved from http://www.christopherteh.com/blog/2011/09/cropwateruse/
[28] Lee, K.E., Mokhtar, M., Hanafiah, M.M., Halim, A.A., & Badusah, J. (2016). Rainwater harvesting as an alternative water resource in Malaysia: potential, policies and development", 126, 218-222
[29] Phang, W.L., & Chan, N.W. (2013). A Study of Consumers' Awareness, Concern and Willingness to Pay in Water Issues in Malaysia. Proceeding of Persidangan Kebangsaan Gerografi & Alam Sekitar Kali Ke-4 – Geografi & Alam Sekitar Dalam Pembangunan dan Transformasi Negara. Universiti Pendidikan Sultan Idris. 181-189
[30] Greech, A. (2014). Household Water Consumption in the Maltese Islands: An Analytical Study. Retrieved from https://www.um.edu.mt/__data/assets/pdf_file/0005/256055/dissertation_summar_AG14.pdf
[31] Sadr, M.K., Memon, F.A., Jain, A., & Gulati, S. (2016). An Analysis of Domestic Water Consumption in Jaipur, India, British Journal of Environmental& Climate Change, 2, 97-115
[32] Willis, R., Stewart, R.A., Panuwatwanich, K., Capati, B., & Giurco, D. (2009). Gold Coast Domestic Water End Use Study. Water: Journal of the Australian Water Association, 36(6), 79-85
[33] Aquaterra, (2008). International comparisons of domestic per capita consumption. Retrieved from https://waterwise.org.uk/wp-content/uploads/2019/09/EA-2008_International-Comparisons-of-Domestic-per-Capita-Consumption.pdf
[34] Portland Water Bureau. (2017) Washing Machines Fact Sheet. Retrieved from https://www.portlandoregon.gov/water/article/305154
[35] Otaki, Y., Otaki, M., Pengchai, P., Ohta,Y., & Aramaki, T. (2008). Micro-components Survey of Residential Indoor Water Consumption in Chiang Mai. Drinking Water Engineering and Science, 1, 17-25
[36] Average Water Use. (2016). Australia: Riverina Water County Council. Retrieved from http://www.rwcc.nsw.gov.au
[37] Hua, T.Y. (2009). Water Demand Management In Malaysia The Big Picture. National Water Services Commission (SPAN)
[38] Gotmare, A.B., (2017). Swarm and Evolutionary Computing Algorithms for System Identification and Filter Design: A Comprehensive Review. *Swarm and Evolutionary Computation,* 32, 68-84
[39] Holland, J.H., (1999). Genetic Algorithms. Scientific American, 267(1), 66-73
[40] Shi, Y., & Eberhart, R. (1998). Modified particle swarm optimizer, IEEE International Conference on Evolutionary Computational Proceeding, 69-73
[41] M.Dorigo, M., & Di Caro, G. (1999). Ant Colony Optimization: A New Meta-heuristic. *Proceedings of the 1999 Congress on Evolutionary Computation-CEC99*, pp. 1470-1477
[42] Fister, J.I., Yang,X.S., Fister, I., Brest, J., & Fister, D. (2013). A Brief Review of Nature-Inspired Algorithms for Optimization.1-7
[43] Abkenar, S.M. (2015). Evaluation of Genetic Algorithms using Discrete and Continuous Methods for Pump Optimization of Water Distribution Systems. Sustainable Computing: Informatics and Systems, 8, 18-23
[44] Cao, K., Feng, X., & Ma, H. (2007). Pinch Multi-Agent Genetic Algorithm for Optimizing Water-Using Networks. Computers & Chemical Engineering, 31(12), 1565-1575
[45] Tsai, M.J., & Chang, C.T. (2001). Water Usage and Treatment Network Design Using Genetic Algorithms. Industrial & Engineering Chemistry Research, 40(22), 4874-4888
[46] Back, T., Hammel, U., & Schwefel, H.P. (1997). Evolutionary Computation: Comments on the History and Current State. IEEE Transactions on Evolutionary Computation*,* 1(1), 3-17
[47] Norharyati, M.A., Khalid, N.E. Mazani,M., & Ezane, A.M. (2007). Cortical Boundary Detection using Gradient Based Genetic Algorithm, Rovisp07, #VIS048

[48] Paek, S.W., Kim, S., & Weck, O. (2019). Optimizations of Reconfigurable Satellite Constellations using Simulated Annealing and Genetic Algorithm. Sensors, 19(4), 765
[49] Mahato, M., Gedam, S., Joglekar, J., & Buddhiraju, K.M. (2019). Dense Stereo Matching Based on Multiobjective Fitness Function - A Genetic Algorithm Optimization Approach for Stereo Correspondence. IEEE Transactions on Geoscience and Remote Sensing, 3341-3353
[50] Abdollahi, H.A., Noaparast, M., Shafaei, S.Z., Akcil, A., Panda, S., Kashi, M.H., & Karimi, P. (2019) Prediction and Optimization Studies for Bioleaching of Molybdenite Concentrate using Artificial Neural Networks and Genetic Algorithm. Minerals Engineering, 130, 24-35
[51] Srinivas, M., & Patnaik, L.M. (1994). Adaptive Probabilities of Crossover and Mutation in Genetic Algorithms. IEEE Transactions on Systems, Man, and Cybernetics, 24(4), 656-667
[52] Maulik, U., & Bandyopadhyay. S. (2000). Genetic Algorithm-Based Clustering Technique. Pattern Recognition, 33(9), 1455-1465
[53] Rajakumara, B.R., & Georgeb, A.(2013). APOGA: An Adaptive Population Pool Size Based Genetic Algorithm, AASRI Conference on Intelligent Systems and Control, AASRO, Procedia, 4, 288 – 296
[54] Jong, K.D., Fogel, D. & Schwefel, H. P. Handbook of Evolutionary Computation. 1997
[55] Eiben, A.E., & Smith, J.E. (2003). Introduction to Evolutionary Computing. New York. Springer.
[56] Schoenauer. M. (1997). Evolutionary Computation Control and Cybernetics, 26(3), 307-338
[57] Cantú-Paz, E. (1998). A Survey of Parallel Genetic Algorithms. Calculateurs Paralleles, Reseaux et Systems Repartis, 10(2), 141-171
[58] Whitley, D. (1994). A Genetic Algorithm Tutorial. Statistics and Computing, 4(2), 65-85
[59] Safe, M., Carballido, J., Ponzoni, I., & Brignole, N. (2004). On Stopping Criteria for Genetic Algorithms. Brazilian Symposium on Artificial Intelligence, 405-413
[60] Aytug, H., & Koehler, G.J. (2000) New Stopping Criterion for Genetic Algorithms. European Journal of Operational Research, 126(3), 662-674
[61] Target 155. (2021). South East Water. Retrieved from https://southeastwater.com.au/residential/learn-about-water/saving-water/target-155/
[62] EPA Water Sense. (2017). Water Efficiency Management Guide: Residential Kitchen and Laundry. Retrieved from https://www.epa.gov/sites/production/files/2017-10/documents/ws-commercialbuildings-waterscore-residential-kitchen-laundry-guide.pdf