Preliminary analysis on the water quality index (WQI) of irradiated basic filter elements

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Abstracts. Simple water filtration system is needed in times of extreme floods. Clean water for sanitation at evacuation centres is essential and its production is possible by using the famous simple filtration system consisting of empty bottle and filter elements (sands, gravels, cotton/coffee filter). This research intends to study the effects of irradiated filter elements on the filtration effectiveness through experiments. The filter elements will be irradiated with gamma and neutron radiation using the facilities available at Malaysia Nuclear Agency. The filtration effectiveness is measured using the water quality index (WQI) that is developed in this study to reflect the quality of filtered water. The WQI of the filtered water using the system with irradiated filter elements is then compared with that of the system with non-irradiated filter elements. This preliminary analysis only focus on filtration element of silica sand. Results shows very nominal variation in in WQI after filtered by non-irradiated, gamma and neutron filter element (silica sand), where the hypothesis could not be affirmed.

1. Introduction
Department of Environmental Malaysia (DOE) have listed a parameters that reflects the quality of water[1]. In this study, six standard main parameters tests were used in order to see the water quality of irradiated and non-irradiated filter element which are Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solid (SS), Acidic and Alkaline (pH) and last but not least Ammonia Nitrogen (NH\textsubscript{3}-N).[2] This experiment was conducted at the National Hydraulic Research Institute of Malaysia (NAHRIM), while the filter elements were radiated at the TRIGA PUSPATI Reactor (RTP) to obtain neuron and gamma effects and SinaGamma facility for...
gamma effects at Malaysian Nuclear Agency. This paper will discuss the comparison between WQI of water after filtered by non-irradiated and irradiated silica sand.

2. Methodology
The simple water filtration system as shown in Figure 1 is very easy to assemble. Basically, the general set-up is made out of small grain materials at the bottom such as sand, and coarse, larger rocks at the top. Contaminated water were poured from the top will go through the filtering elements, removing large impurity particles from the water.

![Figure 1. Simple water filtration system set-up.](image)

For this preliminary study, silica sand is used as the filter element. Sand is the ‘biological filtration’ process of water treatment. This simple system of water purification has been in continuous use since the beginning of the nineteenth century, and has proved effective under widely differing circumstances. It is simple, inexpensive and reliable and is still the chosen method of purifying water supplies for some of the major cities of the world [3]. Practically, sand may be considered to consist of small detrital fragments of rock or mineral particles liberated by mechanical disintegration of parent rock material; or biogenic particles such as shells, shell fragments or chemical precipitates occurring in nature and distinguishable by the naked eye.[4]

The methodology of obtaining the WQI follows the standard laid by the American Public Health Association (APHA)[5]. Table 1 below shows the test parameter and its reference standards.

| Test Parameter                        | Reference Standards                        |
|---------------------------------------|--------------------------------------------|
| pH                                    | APHA 4500 –H⁺B                             |
| Dissolved Oxygen (DO)                 | APHA 4500-O G                              |
| Biochemical Oxygen Demand (BOD)       | In house Test Method MKA TM 04-Determination of BOD based on APHA 5210 D |
| Chemical Oxygen Demand (COD)          | In house Test Method MKA TM 01-Determination of COD based on APHA 5220 D |
| Nitrogen Ammonia (NH₃-N)              | In house Test Method MKA TM 03-Determination of Nitrogen(Ammonia) based on APHA 4500 –NH₃ B |
| Total Suspended Solid (TSS)           | APHA 2540D                                 |
3. Results and discussion

There are 2 factors that influences the WQI which are geometry structure and chemical compound. It is common when a polluted water will get purified after contaminants in the water flows through the grains and micropores of filter. Simple hypothesis predicts that the greater the concentration of micropores in the sand filters, the more impurities will be trapped when water flows through. Secondly, the sand compounds will neutralize and also kills microorganism in the contaminated water. For instance, typical filtration element used to adsorb natural organic compounds, taste and odor compounds.[4]

The results for 6 parameters were recorded. Each parameters have their own classification to define the quality of water either polluted or clean. Table 2 shows the quality class for each parameter that indicate the quality of water. The range for each parameter are very important to calculate the WQI by following the best fit equations for the estimation of various sub index values as shown on table 3.[1]

| Parameter                               | Unit    | Classes       |
|-----------------------------------------|---------|---------------|
| Ammonia Nitrogen                        | mg/L    | < 0.1 0.1 - 0.3 0.3 – 0.9 0.9 – 2.7 > 2.7 |
| Biochemical Oxygen Demand               | mg/L    | < 1 1 – 3 3 – 6 6 – 12 > 12 |
| Chemical Oxygen Demand                  | mg/L    | < 10 10 – 25 25 – 50 50 – 100 > 100 |
| Dissolved Oxygen                        | mg/L    | > 7 5 – 7 3 – 5 1 – 3 < 1 |
| pH                                      | -       | > 7 6 – 7 5 – 6 < 5 > 5 |
| Total Suspended Solids                  | mg/L    | < 25 25 – 50 50 – 150 150 – 300 > 300 |
| Water Quality Index (WQI)               | -       | < 92.7 76.5 – 92.7 51.9 – 76.5 31.0 – 51.9 > 31.0 |

Table 2. DOE Water Quality Index Classification.

| Sub Index (SI) | Range               |
|----------------|---------------------|
| Dissolved Oxygen (DO) (% saturation) |SIDO = 0 for x ≤8SIDO = 100 for x <92SIDO = -0.395 + 0.030x$^2$ - 0.00020x$^3$ for 8 < x < 92|
| Biological Oxygen Demand (BOD)   |SIDOD = 100.4 - 4.23x for x ≤ 5SIDOD = 108* exp(-0.055x) - 0.1x for x > 5|
| Chemical Oxygen Demand (COD)     |SICO = -1.33x + 99.1 for x ≤ 20SICO = 103* exp(-0.0157x) - 0.04x for x > 20|
| Ammonia Nitrogen (NH$_3$-N)      |SIAN = 100.5 - 105x for x ≤ 0.3SIAN = 94* exp(-0.573x) - 5* 1 x - 21 for 0.3 < x < 4SIAN = 0 for x ≥ 4|
| Suspended Solid (SS)             |SISS = 97.5* exp(-0.00676x) + 0.05x for x ≤ 100SISS = 71* exp(-0.0061x) + 0.015x for 100 < x < 1000SISS = 0 for x ≥ 1000|
| Acidic and Alkaline (pH)         |SlpH = 17.02 - 17.2x + 5.02x$^2$ for x < 5.5SlpH = -242 + 95.5x - 6.67x$^2$ for 5.5 ≤ x < 7SlpH = -181 + 82.4x - 6.05x$^2$ for 7 ≤ x < 8.75SlpH = 536 - 77.0x + 2.76x$^2$ for x ≥ 8.75|
The letter “x” in table 3 represents the concentration of each parameter in mg/L except for pH. After each sub index for each parameter has been calculated, the values will be substituted into equation 1 to calculate Water Quality Index, WQI.

\[
WQI = (0.22 \times \text{SIDO}) + (0.19 \times \text{SIBOD}) + (0.16 \times \text{SICOD}) + (0.15 \times \text{SIAN}) + (0.16 \times \text{SISS}) + (0.12 \times \text{SIpH}) \tag{1}
\]

where,

- \text{SIDO} = \text{Sub Index DO (} \% \text{ saturation)}
- \text{SIBOD} = \text{Sub Index BOD}
- \text{SICOD} = \text{Sub Index COD}
- \text{SIAN} = \text{Sub Index NH3-N}
- \text{SISS} = \text{Sub Index SS}
- \text{SIpH} = \text{Sub Index pH}

\(0 \leq WQI \leq 100\)

The calculated WQI is tabulated in table 4. Silica sand were used as filtration element and the quality of water resource label as \textit{Original}. Water were filtered through 3 types filtering elements, which are firstly the non-treatment of silica sand call as non-irradiated, secondly are the silica sand treated by the gamma and thirdly, silica sand irradiated with neutron. The filtration experiments are repeated 3 times for all gamma and neutron filters.

The results shows nominal changes in WQI between neutron-irradiated and non-irradiated silica sand of about 4\% positive. Meanwhile for gamma-irradiated filters also shows nominal changes but inconsistent results of positive and negative WQI of about 4\%. The variation in the results show larger percentage of uncertainties than the variation between different samples. Results from neutron-irradiated sand sample could slightly show signs of hypothesis approval.

A few factors might be contributed to the results in this lab analysis. Firstly, might be due to the water source use in this analysis. Refer to the result of original, it indicate that the water resource is already clean with WQI is 86. The value of Nitrogen Ammonia (NH\textsubscript{3}-N), Chemical Oxygen (COD), Total Suspended Solid (TSS) are in class I (refer table 2). As the water resource initially unpolluted, might be the filtration process done without need to filter any contaminated and unnecessary particle.

Secondly, the time contact of water with the silica sand would be the one of the factor that effect the results. During the filtration process in this experiment, only half of the syringe are filled with silica sand, hence water flew through the silica sand for a short period of time. Thus, the data obtained shows very small amount of filtration.

Thirdly, it can be assumed that the treated silica sand might be have limitation in filter some of the parameter. The commercial filtration system like membrane have their own capabilities. The ultrafiltration membrane process could not filter monovalent and multivalent (Sodium chloride, magnesium sulphate and others) meanwhile reverse osmosis membrane process only allow water to pass through[6]. Hence, this experiment expected to have this kind of restraint.
Table 4. Results of WQI.

| Parameter               | Unit  | Original | Non irradiated | Gamma 1 | Gamma 2 | Gamma 3 | Neutron 1 | Neutron 2 | Neutron 3 |
|-------------------------|-------|----------|----------------|---------|---------|---------|-----------|-----------|-----------|
| Dissolved Oxygen (DO)   | mg/L  | 5.98     | 7.74           | 7.74    | 7.67    | 7.75    | 7.73      | 7.88      | 7.9       |
| %                       |       | 74.3     | 94.1           | 94.4    | 93.8    | 93.8    | 94.5      | 95.7      | 96.5      |
| Biochemical Oxygen Demand (BOD) | mg/L | 2.5      | 0.8            | 2       | 2.5     | 3.1     | 2         | 2.8       | 2.5       |
| Chemical Oxygen (COD)   | mg/L  | 7.62     | 5.93           | 7.05    | 6.01    | 6.47    | 6.41      | 7.19      | 6.39      |
| Nitrogen Ammonia (NH₃-N) | mg/L | 0.344    | 0.338          | 0.324   | 0.342   | 0.326   | 0.402     | 0.362     | 0.371     |
| Total Suspended Solid (TSS) | mg/L | 10       | 14             | 10      | 15      | 13      | 24        | 13        | 21        |
| pH                      |       | 6.66     | 6.58           | 6.64    | 6.72    | 6.79    | 6.61      | 6.86      | 6.88      |
| WQI                     |       | 86       | 84             | 83      | 82      | 90      | 89        | 90        | 89        |
| ΔWQI                    | %     | 0%       | -2.33%         | -3.49%  | -4.65%  | -4.65%  | 3.49%     | 4.65%     | 3.49%     |

4. Conclusions
The results shows nominal changes in WQI between irradiated and non-irradiated silica sand. Irradiated silica sand does not improve the concentration of micropores or change the microstructure. Further analysis need to be conducted in order to get a better understanding of the phenomenon in this experiment. Next step will be to place more emphasize on the 3 factors discussed which were the source of water, time contact and limitation of filter. Future studies will include metallurgical analysis which are also important to obtain the amount of micro-structure changes in the silica sand due to the irradiation. X-ray Diffraction (XRD) and Scanning electron microscope (SEM) will be used for this microstructure analysis [7].

5. References
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