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Drinking water treatment plant process optimization : A case study of Kalu river basin, Sri Lanka

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Abstract: Across the past decade, increasing water demand has been identified in Sri Lanka. The National Water Supply and Drainage Board is responsible for supplying potable drinking water to Sri Lanka people. There having various rural, urban water supply schemes are operated under that. Apart from that, the private sector water supply systems are also there. Thus, this paper focuses on investigating Sri Lankan drinking water treatment's operation procedure and optimizing its process by exemplifying the Kalu river basin as a case study.

Keywords: Coagulation, filtration, process optimization, sedimentation, sludge management, water treatment.

1 INTRODUCTION

The increment of water demand is an essential issue over the last century due to the urbanization, population increment, changing lifestyle, etc., in Sri Lanka. Implementing water treatment plants has been one of the solutions that can be seen in the past few years. More than 20 drinking water treatment plants are currently operated to supply adequate drinking water to the community. A typical conventional drinking water treatment consists of coagulation, flocculation, sedimentation, filtration, and disinfection. Depending on the intake of raw water quality, these processes must be varied. These processes require high operating costs, high technological machinery, considerable chemical cost, high utility cost, and a large labor force. Therefore, the drinking water treatment plant process's optimization is a critical issue that needs to be a concern. To gain the most efficient output from the drinking water treatment sector, it is essential to have new concepts to optimize its operation procedure, manage styles, innovate technologies, and think beyond the typical box. To do that, understanding the phenomenon of the drinking water treatment process is an important thing. This paper presents an overview of the Sri Lankan conventional drinking water treatment process and its issues. The later part will propose some methods to optimize the treatment process to give maximum treatment performance to the Sri Lankan community.

2 CONVENTIONAL WATER TREATMENT PROCESS

The main objectives of the Sri Lankan water treatment process are,

- To protect the consumer's health by ensuring bacteriological safe.
- To make sure it will acceptable by the consumers depending on the aesthetic quality, taste, odor, and color.

- To make it suitable for various processes like industrial steam generation, dyeing, etc.
- To preventing scaling and corrosion in water distribution pipelines.

So, depending on the water source, raw water quality, required end-user quality, availability of economic resources, and Operation and Maintenance, the water treatment process will vary with the different infrastructure and process stages. This article focus on the drinking water treatment process, Sri Lanka by taking the Kalu river basin as the case study. The common water treatment process in Sri Lankan is shown in Fig. 1 [1].

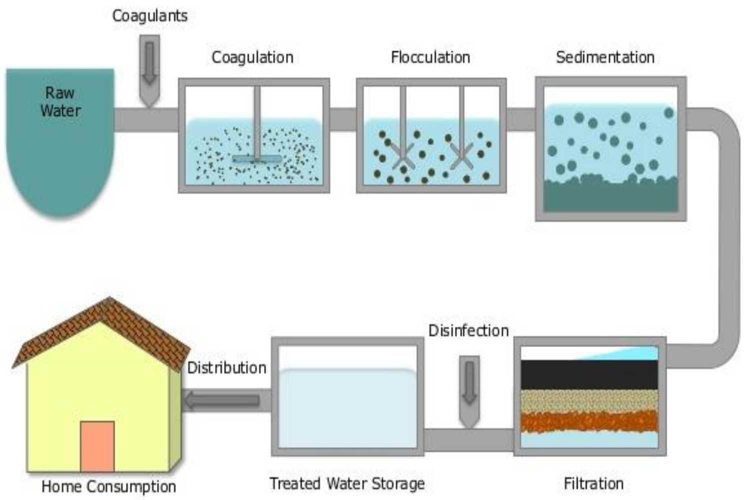

Fig. 1. Water Treatment Process

2.1 Raw water extraction

The water treatment process begins with the raw water extraction step. Raw water sources can be identified as groundwater, surface water, ocean water, spring water, etc. In the Sri Lankan water treatment process, intake can be taken as a river, lake, well, or even maybe the ocean [2]. This article focuses more on the Kalu river basin as intake. Therefore surface water will be taken as the raw water source for the drinking water treatment process. There mainly having two water treatment facilities are located at the riverside of Kalu Ganga. Each of these having a different treatment process based on the raw water quality. The riverside of Ratnapura to Kalutara considers as the catchment area of those plants.

2.2 Screening

Raw water from the river usually contains large floating objects, fibrous material, plastics, papers, rags, leaves, wood residuals, or other foreign objects. Therefore, the screening's main objective is to protect pumps, valves, pipelines, impellers, and other appurtenances. objective is

Screens are classified based on the,

- Opening size: coarse, medium, fine
- Configuration: Bar screens, Mesh screens
- Cleaning Method: Manual, Mechanical, Raked, Water jet
- Screen surface: Fixed, Moving

Fig. 2 and Fig. 3 illustrate the common screen types in Sri Lankan water treatment facilities.

Fig. 2. Coarse screen [3]

Fig. 3. Fine screen-drum type [3]

The fine screens typically use to remove materials that the coarse screens cannot remove. There have various types of fine screens, and usually, those are operated by plant technicians based on the raw water quality data. Water sprayed at high speed, and all the trashes are flows into a small drain. Trash handling will be done manually.

2.3 Coagulation

After the screening, raw water will pump to a distribution chamber for the coagulation process. Aeration is the next major step in many treatment processes. If water does not carry enough oxygen, then the treatment will be difficult. Most of the water sources are less oxygen due to bacterial pollution. The addition of oxygen is therefore done through the aeration structures. There having various aeration types and Fig. 4 and Fig. 5 are shown some of them.

Fig. 4. Cascade aeration type 1 [4]

Fig. 5. Cascade aeration type 2 [4]

Some plants use pre-chlorination/pre-lime processes to adjust the raw water pH before the coagulation process has taken place. All these are based on raw water quality to enhance the purification process. Coagulation removes many particles, such as dissolved organic carbon, which makes water difficult to disinfect. Because of that, less chlorine must be added to disinfect the water. In the coagulation process, use various chemical coagulants like,

- Aluminum Sulphate (Alum)
- Poly Aluminium Chloride (PAC)
- Ferrous Sulphate
- Ferric Sulphate
- Ferric Chloride

that having positively charged particles[2]. When we added coagulant to the raw water it will start to neutralize the negatively charged particles in the raw water which will initially cause the colloidal particle to become destabilized and clump together to form floc. There having various purposes of coagulation like,

- Removal of turbidity
- Removal of colour
- Removal of bacteria and other organisms
- Algae removal
- Removal metals and organic matter.

Usually, alum (Aluminium Sulphate Octadecahydrate- $Al_2(SO_4)_3.18H_2O$) is a commonly used coagulant for many drinking water treatment plants, Sri Lanka. The laboratory jar test will be used to determine the required alum amount. Some plants use hydraulic jump techniques to disperse coagulant species efficiently.

2.4 Flocculation

Flocculation occurs simultaneously as coagulation and is a much slower process that requires a gentle mixing allowing the particles to come into contact and form more settleable floc. Most of the plants are using the slow and hydraulic flocculation method and allow water to flows in zig-zag order in order to create more flocs. Most flocculation basins are designed with volume increasing order for efficient flow. Fig. 6 shows the commonly used flocculation basin type (hydraulic) in Sri Lanka.

Fig. 6. Hydraulic flocculation chamber [5]

2.5. Sedimentation

After the flocculation, sedimentation will be taken place. The main objective of sedimentation is to remove the settleable solids in water by gravity. The sedimentation basin slows the flow of water, allowing suspended solids to settle in the form of sludge. After settling, clarified supernatant leaving at the top of the sedimentation tank as overflow and concentrated sludge leaving the sedimentation tank's bottom as underflow. Electrical sludge scrapers use to collect those sludge. The scrappers move slowly along the tank floor, pushing the sludge into the sludge pockets/ or drains located at the corner or bottom of the tank. Collected sludge goes to the sludge management process. Fig. 7 and Fig. 8 show some of the common sedimentation structures that can be seen in Sri Lanka.

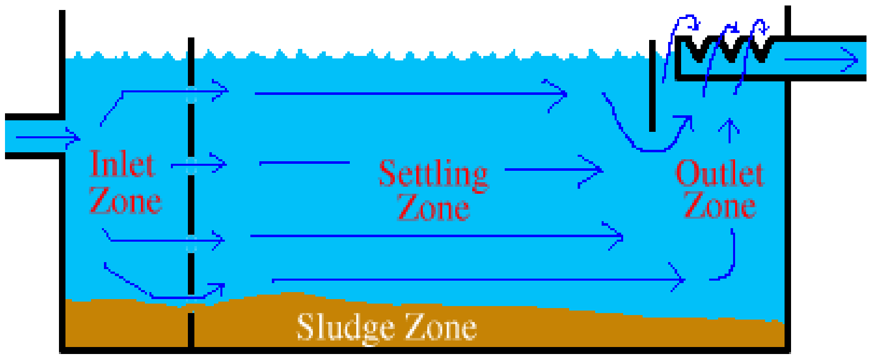

Fig. 7. Rectangular sedimentation tank [6]

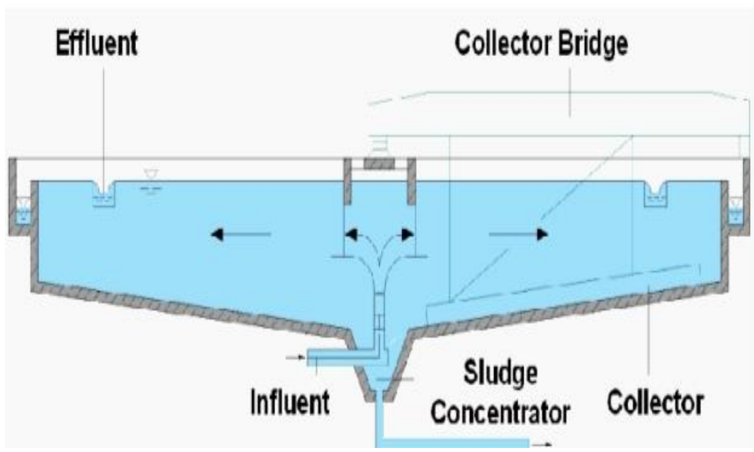

Fig. 8. Circular sedimentation tank [6]

2.6. Filtration

Filtration is a process that consists of passing water through a filter media to remove particles in the water. Filtration removes more than 99% of bacteria. There having various filtration methods like rapid sand filtration, slow sand filtration, etc [2]. Rapid sand filtration is the common method we can see in Sri Lanka. It is a physical method used to remove the suspended solids from the water. The filters are generally cleaned with a backwashing system. Usually, this backwashing step conducts per every 48h. Backwash method compromised by air blowing followed by passing water and air mixtures (rub the filter media to remove particles) to clean the water. Fig. 9 presents the shape of a rapid sand filtration tank.

Fig. 9. Filter basin [7]

2.7. Disinfection

This is the last step of many drinking water treatment facilities to destroy pathogenic bacteria and also ensure of preventing & spreading waterborne disease. There having various disinfection methods like the addition of gas Cl_2, ozone, and ultraviolet radiation. The majority of Sri Lankan water treatment plants use gas Cl_2 as a disinfection method [2]. This process must also protect the distribution network against the development of bacteria and other organisms. In many treatment facilities, this gas Cl_2 injecting process is done by maintaining the residual chlorine level at 0.8-0.9 at the endpoint. Chlorine is a highly toxic chemical; therefore, many plants engaging the safety precautions to prevent any Cl_2 leakages. Apart from that, some plant uses various chemical for the pH adjustment after addition of gas Cl_2.

2.8. Clearwater sump

After the treatment process, the treated water store in a clear water tank for further distribution to the end-users. This is the common treatment process in the majority of treatment facilities in Sri Lanka. Therefore, the optimization process should be carried out by identifying its issues.

3 TREATMENT PROCESS OPTIMIZATION

Throughout the process, the water is generally clean, but the efficiency is minimum. Usually, the following operational issues can be identified in Sri Lankan treatment facilities,

3.1. Insufficient capacity to cater to the existing demand

The most massive problem related to Sri Lankan drinking water plants is the huge difference between the design capacity and the plants' actual demand. Approximately, Kalu river basin facilities have 1,20 000 m3 per day, while actual demand sometimes exceeds 1,30 000 m3 per day. All the plants put their maximum effort into providing water to their consumers. However, they are not in a position to cater to the current demand. With the rapid growth of the population, the number of consumers increases dramatically; thus, the forecasted demand is also rapidly increasing. It causes the plant to work without stopping to provide a higher volume of treated water than possible. This eventually causes the overloading of the plant facilities [8].

Suggestions

As the population and the number of water consumers increase day by day, it is better to notice that building a large-scale plant is more economical, easy, and feasible than building two plants with smaller capacities. Even though 'Kalu Ganga' having two regional plants, it is difficult to cover the existing demand. Even when several smaller plants are to be implemented nearby, it is suggested to go for one larger plant.

3.2. Problems due to gem and sand mining

The riverside of Rathnapura to Kalutara considers as the catchment area of Kalu Ganga drinking water treatment facilities. So gem and sand mining are among the major occupation of the residents. So there having plenty of illegal sand mining locations near the 'Kalu Ganga' catchment area. These illegal anthropogenic activities in surface water bodies cause many problems, including increasing water turbidity, dropping the water table and landslides at up steam, etc. [8]. When designing the treatment plants, the relevant water source's existing turbidity is used to design flocculation basins, sedimentation tanks, and filters. However, the turbidity level will show a huge increase due to the mining issues than the anticipated value. Thus, the capacity of the existing treatment methods is not sufficient to purify that highly turbid water. Usually, 'Kalu Ganga raw water turbidity lies between 20-130 NTU. But sometimes it dramatically increased up to more than 200NTU. Plant technicians cannot settle the plant in such cases because they cannot find the exact alum dose suddenly. As a common practice, aluminum sulfate is applied according to the jars test results. So the test will take approximately 30 min. If we cannot find the exact alum dose immediately, the raw water will come to the sedimentation and filtration basin. So in such cases, the plant should be shut down to settle and approximately take 24 hours to recover the plant.

Another impact is that the intake water level may drop dramatically due to sand removal. It is also sometimes in regional plants near the coastal area; seawater comes to the raw water intake. So raw water conductivity increasing more than 1500µs/cm, and chloride level also exceeding up to an uncontrollable limit.

Suggestions

- Sand and gem mining cause massive problems to the river catchment. However, there is an act prohibiting the mining of sand/gem within 2km upstream and downstream from an intake structure. This should be acknowledged to the miners, and if the mining prevails, legal actions should be taken to put an end to it [8].
- This dramatic change of turbidity level sometimes happens due to heavy rain. Therefore it is better to think beyond the conventional operation. In some WTPs in Sri Lanka, they use polymers as a coagulant. Therefore, the anionic polymer can be suggested to optimize coagulation efficiency under higher turbidity conditions. Generally, organic polymers are much faster processing and greater operational stability and reliability than inorganic coagulants like alum. Polymer-based coagulant creates more flocs fastly than the alum-based coagulant at high turbidity. Therefore polymer-based coagulant will be the best solution for the high turbidity levels [9].

3.3. Catchment pollution

However, with the increase in population, deforestation, and industrialization, the catchment areas' conditions are dramatically changing day by day. Sometimes, the surface water becomes contaminated with industrial waste from BOI industries, industrial zones, rubber factories, agriculture chemicals from rubber, tea, paddy plantation, and domestic solid waste and wastewater. This is a critical issue we can see in many treatment facilities, Sri Lanka.

Suggestions

- All industries within the catchment area should discharge their wastewater according to the SLS 652:1984 wastewater discharge limits. If they exceed limits, we should introduce proper wastewater treatment methods, introduce rehabilitating wastewater systems, and implement legal actions for violations of rules and regulations according to the Sri Lankan Environmental Acts [8].
- Awareness programs should conduct regarding the possible water contaminations and their health effects.
  Pesticides and heavy metals concentration in raw water should be tested periodically.

3.4. Maintenance difficulties

It is insisted that the rapid sand filters need to be back washed frequently to clean them from mud particles collected in the filter media. And also, sand should be replaced every year. The operators tend to utilize the plant's maximum available capacity by using all the filters when the demand is high. So backwashing of filter frequency may be reduced. Thus it causes the efficiency of the filter to be reduced by a considerable amount. In the long term, it can cause mud formation in the sand bed and lead to refilling the filter media. Another major problem is that the incorrect readings of online operating systems (analyzer rack). From that, plant technicians cannot find the correct, current water quality. Therefore maintenance problems will arise in such cases in many treatment facilities.

Suggestions

- Filter backwashing can be done at night where electricity demand is low.
- PVC granules can be suggested as filter media instead of conventional sand. PVC granules have less specific gravity compared to sand. Therefore larger particles remain on top after backwashing. This type of media also provides a larger depth for filtration and improves performance by removing larger suspended particles at the initial stage. Filtration efficiency is also higher than the conventional sand filters, and also backwashing is more effective. The backwash water requirement of these types of filters is also less than the conventional sand filter [10].
- Proper Maintaining and cleaning, calibration schedule of the analyzers rack, clean the sensors regularly, maintain a proper stock of spare parts will definitely improve the efficiency of the online operating system, which is called analyzer rack.

3.5. Alternative coagulants

Instead of aluminum sulphate we can substitute this into another natural, available and cheaper coagulant. On the other hand, those coagulants reduce sludge generation.

- Bentonite- It is effective in the treatment of low turbidity raw water. It provides an eco-friendly and economical method for the treatment of water as compared to chemical-based methods.
- Drum stick can be used for high turbidity raw water, and Strychnospotatorum and Cactus opuntia can be suggested to improve the quality of the filtered water [11].

3.6. Determination of optimum coagulant dose using new technologies

Alum is applied according to the jars test results. The problem is that it takes more time to determine the optimal dose of aluminum sulphate related to different raw water characteristics. Many Sri Lankan water treatment facilities are currently engaging with the manual method to determine the coagulant's quantity to apply experimentally based on the jar test results. This operation should be repeated by plant technicians each time when the quality of raw water changes. The aluminum sulphate is the compound that can be mathematically modeled, and therefore, its value can be estimated according to the data available in the treatment plant. Under-dosing of coagulants issues can lead to poor quality drinking water. In contrast, over-dosing of coagulants leads to many operating problems, including less efficiency in sedimentation and filtration tank, healthy problems, and increased purification cost. Therefore a model should be developed based on the relationships between raw water quality characteristics and the optimum coagulant dosage rate. This can be done using past available historical dosing data in the treatment facility. Artificial Neural Network (ANN) techniques can also be suggested to control this coagulant dosing issue [12].

3.7. Inclined plates to improving sedimentation efficiency

Inclined tubes and plates can be suggested for the sedimentation basins to allow higher loading rates. This technology relies on the theory of reduced-depth sedimentation. So, particles need to settle on the surface of the tube or plate below for removal from the water flow. Generally, a space of two inches can be suggested to provide in between tube walls or plates to maximize settling efficiency. This will also lead to an increase in the water cleaning process much faster [13].

3.8. Implementing smart metering technologies

Smart technologies like Automated Meter Reading (AMR) solutions and Advanced Metering Infrastructure (AMI) can be suggested for smart metering. Those technologies can be used to monitor the distribution network and minimize non-revenue water waste. AMR automatically gathers consumption, status information from water meters without the need for a manual meter reading. Hence, it will improve the accuracy of data collection. AMI can make decisions based on performance. It is a better robust solution than AMR, including smart meters, communication networks, and data management systems that enable two-way communication between utilities and customers [14].

Besides all these things, sludge generation is a critical problem in Sri Lankan drinking water treatment facilities that need to be concerned. A considerable amount of sludge is produced due to the backwashing of rapid sand filters and the accumulated sludge's release process in sedimentation tanks. Generated sludge will go to the further purification process. Approximately 9000m3 of sludge will be produced in one month and there is no method to do with the treated sludge. Therefore, the sludge management process also needs to be optimized.

4 SLUDGE MANAGEMENT PROCESS

Usually, drinking water treatment sludge mostly contains aluminum sulphate (alum) as it is the chemical we used in the coagulation process. Therefore rather than dumped those in a landfill, it is better to reuse the sludge for useful things. The following solutions can be suggested for the sludge management process.

4.1. Use in Constructed Wetlands/ Reed Beds

We can grow plants in that sludge collection area and make it as a wetland as the Fig. 10. So, various combinations of soil, sand, and gravel have been utilized as substrates in the wetlands. Alum-based sludge has the potential to be used in constructed wetlands to enhance phosphorus reduction. In addition to that, it absorbs various pollutants since typical alum sludge are rich with aluminum, iron, and calcium residues, which are strong adsorbents for pollutants in wastewaters [15].

Fig. 10. Wetland construction [16]

4.2. Soil conditioner/Fertilizer

Sludge can be used as a soil conditioner/fertilizer by checking the NPK level(nitrogen, phosphorus, potassium). If the nitrogen level is not good, we can add cow dung, some nitrogen high plants, or urea. Sludge utilization as a soil conditioner can improve soil structure, porosity, hydraulic conductivity, water retention capacity, organic matter content, and nutrient levels because this sludge contains a substantial amount of macro and micronutrients and organic matter. The utilization of sludge as a soil conditioner in the agriculture sector is often observed as a sustainable long-standing method to enhance nutrient recycling and improve soil characteristics [17].

4.3. Brick making

Dried sludge can be mix with cement and used for brick making. This sludge is almost non-hazardous, and the chemical composition of the sludge is similar to the clay used in cement production, so it is suitable for brick production. First, we should check the chemical composition of the sludge. Otherwise, the brick will tend to breakable [18]. Fig. 11 shows a constructed brick from the drinking water sludge.

Fig. 11. Drinking water treatment sludge to brick[19]

4.4. Aluminum recovery from sludge

The removal sludge contains thousands of aluminum particles. Rather than disposing of them at the landfill, it is better to recover them. Sometimes, aluminum content in the sludge after coagulation of the drinking water treatment process is 39% by weight. Acidification techniques, membrane-based separation techniques can be suggested for the Al recovery process. Recovered pure aluminum can be reconstituted to generate new coagulants for reuse in the water treatment process [20].

4.5. Phosphorous adsorbent

The utilization of this sludge can be used as an adsorbent for phosphorus removal in wastewaters. This adsorption capacity depends on the pH level. The oven-dried method can be used for utilization. Definitely, this will be a low-cost and reliable sustainable solution for P-removal for small and medium-sized municipalities [21].

4.6. Wastewater coagulant

Aluminum-based sludge also can be e utilized as a coagulant to remove oil, grease, chemical oxygen demand (COD), and suspended solids from wastewater [20].

4.6. Used as potting material

Dried sludge can be used as a potting media, which can improve the soil aeration and available water holding capacity. Alum-based sludge utilization as a potting medium has a huge potential for the future world because some existing potting media like peat are non-renewable, high cost, and environment threatening material. Therefore this drinking water sludge can be used as a tailor-made potting media by manipulating all required nutrients [22].

In addition to that, other industrial uses of this sludge can be suggested as; palletized softening sludge can be used as a soil conditioner, animal feed, dispersion dye, and filler material, dyes, and paints, for lake restoration, and tile production. Therefore, treatment facilities can be sold this sludge to relevant industries for further utilization [23].

Apart from all the above-mentioned suggestions, we can utilize the plant energy consumption by,

- using variables speed drives on pump motors.
- using lighting controls upgrade.

- replacing existing pumps and motors with more efficient pumps and motors.
- reducing dependency on CEB electricity by using rooftop solar systems, etc [24].

5 Conclusion

Drinking water treatment process optimization is essential in its process and effective in reducing costs (operating, maintenance, utility, etc.), sludge utilization, purification efficiency enhancement, etc. So, the paper presents many practical suggestions that can be used for the Sri Lankan drinking water treatment processes. The proposed sludge management methods will reduce current emerging sludge production issues in many water treatment plants. The suggestions mentioned for the treatment process will be given several economic and operational benefits. It reduces the dependency on chemical coagulants, reduces sludge production rates, enhances turbidity removal efficiency, and reduces the energy demand. Therefore, it is better to apply those approaches/practices to the real emerging issues in the Sri Lankan drinking water sector.

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