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Utilizing hydraulic modelling and Geographical Information System (GIS) in developing a water distribution network for reclaimed water

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Abstract. Rapid development has increased water demand, combined with population growth, water scarcity, climate change, and rapid economic growth, are driving factors for water reclaim. This paper reviews previous research on developing a water distribution system for delivering reclaimed water in order to mitigate the industry's growing water demand. As a result, reclaimable wastewater should be identified in order to establish links between urban and industrial infrastructure planning and water reclamation. Correspondingly, it is tasked with the responsibility of developing low-cost water treatment for industrial water reclamation. Simultaneously, a reliable water distribution network is required to deliver reclaimed water. This can be accomplished through the use of hydraulic modelling and GIS to analyse, manage, and develop the water distribution network in response to a growing supply demand. Hydraulic modelling is used to calculate and analyse the demand for the water supply over a specified time period based on daily water use. Additionally, it computing the appropriate parameter for the pipeline in order to deliver an adequate amount of pressure to the consumer efficiently. The developed hydraulic model was then integrated into GIS to facilitate the network layout and visualization of the water distribution system. Apart from that, in order to fully implement the concept of reclaimed water and its delivery via a water distribution system, several factors must be considered, including public acceptance, economic viability, environmental stewardship, technical operation, and health risk.

1. Introduction

Rapid and continuous development of industrialization and urbanization worldwide, especially in developing countries, has led to increasing demand for water resources. As the economy grows substantially, the need for resources, most notably water, has reached an all-time high, with low utilization and non-sustainable use of water resources; this may cause water shortages in the future. Therefore, an alternative water resource requires accommodating the increasing water demand and substituting the freshwater need for industrial and non-drinkable purposes. The most common practice is to replace freshwater with reclaimed or recycle water as an alternative for non-potable use [1]. Reclaimed water refers to water collected from various sources that have undergone treatment or

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processing wastewater to make it reusable for different purposes such as groundwater replenishment, agricultural, landscaping, irrigation, non-potable use and industrial application, direct or indirect water supply, and environmental restoration.

The advance of wastewater treatment technology has increased the application of reclaimed water as it can effectively process and remove pathogens, biodegradable material, and nutrients [2]. However, using reclaimed or recycled water for drinking is relatively poor well-known as public still get a terrible impression of using water mainly for sanitation or flushing toilets as drinking water. Although most despise of the idea using recycled water as drinking water, some countries like Australia, Singapore, Namibia, and the United States of America already drinking it, showing that the wastewater can be treated and purified until it is safe, clean and drinkable that it can ease water shortages [3]. In addition, wastewater reuse provides economic and environmental benefits such as improving soil quality, saving water cost, decreasing pollutant emission, and promoting the development of wastewater reuse.

To develop a fully operational reclaimed water distribution system, need to develop wastewater treatment plant, water resources, and reclaimed water management, economic and financial analysis, and public acceptance. However, wastewater needed secondary treatment and pipeline networks requires expensive capital to implement [4]. Therefore, this paper aims to review the past study on developing a water distribution system to deliver reclaimed water to alleviate the increasing water demand in the industry.

2. Industrial water demand

The rapidly growing economy has boosting industrial producing capacity to the roof. Thus, the demand for resources, especially water, has steadily increased to cope with their growing operation. Therefore, many recent studies have been conducted on forecasting water demand need for industrial activity and evaluating the total consumption of water resources in various industries. For instance, the following studies were conducted using extensive and low-carbon economic modes to forecast water demand in the Baiyangdian Basin aims to analyse the effect of extensive and low-carbon economic development mode on total regional water demand and different water users. The water demand forecast of the research region includes productive, ecological, and domestic parts. The study also correlated economic growth and energy consumption. Therefore, a linear regression analysis was used to develop critical parameters of the Cobb-Douglas productive function model of the Baiyangdian basin with Statistical Package for the Social Sciences software SPSS. From the analysis, the water demand of the primary industry like agriculture, forestry, animal husbandry, and fishery accounts for more than 60% of the total water demand. Results showed that the gross water demand of the primary industry would decline, while the secondary (general industry and construction) and tertiary industries (transportation, service, banking, insurance, medical treatment, and education would expand [5]. There are limitations of these methods, however, is that they lack data to forecast the irrigation, economic growth rate, and ecological water demand within a stream.

Research has gradually broadened to water demand by a different type of industry, as shown in a study conducted on industrial water demand for agro-processing and beverage industries in Rwanda. The study emphasizes the importance of water in food processing as a product ingredient, operating essential equipment such as boilers and cooling towers, and for cleaning and sanitation purposes to ensure a sufficient level of hygiene. It is found that industrial water used for some industrial production in Rwanda is within the recommended limit, for example, maize flour 2 m^3/ton and breweries such as beer production industry 4 to 4.5 m^3/m^3 and carbonated soft drink industries 4 m^3/m^3 against an internationally approved water consumption of 2 m^3/ton, and 6.5 m^3/m^3 respectively. However, the sugar-making industry 29/m^3/t, the Tomato paste production industry 6m^3/ton, and the Meat processing industry 5/m^3/t exceeded the internationally recommended, which are 25/m^3/t, 3.58 m^3/ton, and 2m^3/ton. The findings show that brewing industries consume more water than any other kind of industry in Rwanda as it could relate to the amount of production and demand for the product [6]. The limitation of this study is that the relationship between climate change, urbanization, and industrial water demand has not been considered because of data availability.

A more common technique to predict industrial water demand, water deficits, and their future uncertainty in Beijing is by using statistic and econometric regression models to modelling and simulated the industrial water demand of Beijing municipality in China. The study conducted to analyse and predict industrial water demand, water deficits, and their future uncertainty in Beijing using statistic and econometric regression models. Results showed that from year 2008 to 2015, the industrial water demand decline from 6.31x10^8 m^3 to 4.84x10^8 m^3 in Beijing. The continuously decreasing water consumption is mainly due to enhanced water-saving policy, more efficient water use, the increasing use of reclaimed wastewater. The modelling results showed that the industrial water demand of Beijing would decrease with an increasing growth rate of industrial technology and increasing volumes of reclaimed wastewater during this period. However, it is still questioned that are still not discussed as why the industry face water deficit even though the simulation provides optimistic water usage from the four scenario been simulated [7]. It is suggesting that the authors did not include environmental changes in simulation as environmental change in the term of climate had an adverse effect on water resources. From studies, forecasting accurate water demand for future consumption requires more consideration that needs to be taken into account instead of population, economic, and industrial growth. The next crucial aspect that needs to consider is climate change. Climate change has drastically affected global rainfall intensity, relative humidity, temperatures, and wind in recent years disrupting already scarce water resources. This claim support by Wang et. al., [8] studies claimed water demand estimates to increase by 28% due to climate change from 2020 to 2030 based on the average temperature. Therefore, further theoretical and systematic research on climate change and uncertainties in forecasting water demand relationship with urbanization and industrial water demand must be investigated.

3. Reclaimed water for industry

Reclaimed water had become more prominent this past year as it gives excellent opportunities to overcome water shortages and encourage optimum use of water resources. Most of prior research suggests that reclaimed water has different usage depend on the industry [9]. Increased water efficiency can be achieved through the reduction of water intake and the reduction in wastewater discharged. The challenges for the industry in integrated wastewater management include resource efficiency in areas such as energy, water, and raw materials while maintaining a balance of production, expansion and supporting economically sustainable wastewater treatment. Integrated waste water management solutions include water reuse, freshwater substitute, recycling industrial waste, zero liquid discharge, sanitation, stricter regulations, and corporate responsibility.

In sub-Saharan, Africa uses water reclamation for their industry to cope with water scarcity. The study shows that critical climate changes provide another level of risk to water security, as alterations in precipitation and temperature affected the yearly precipitation, soil moisture, and water runoff and expected to decline as temperature rises may push further water shortages. Thus, other drinking and other household water supplies become more accessible by reclaiming water for industrial needs. Reclaimed water has the potential to be used in a wide range of applications, including resource extraction, thermal power plant cooling, chemical manufacture, metal processing, paper mills, and textile manufacturing [10]. However, existing research has multiple limitations in terms of representing stakeholder involvement. Extensive research on the acceptance of recycle water for industrial purposes and the incorporation of water reclamation options in integrated wastewater infrastructure should be considered.

Over time, an extensive study has developed on various industrial wastewater treatments and prominently wastewater in chemical industries in India using current technologies. Methods and technologies for industrial wastewater reclamation are bio-refineries wastewater treatment using constructed wetlands, post-harvest interventions, membrane bio-reactors system, two-phase partitioning bioreactor, and up-flow anaerobic sludge blanket technology UASB reactor. The issue in incorporating wastewater treatment is to identify low-cost, low-tech, user-friendly technologies that prevent compromising large wastewater-dependent industries while protecting valuable natural resources from degradation. For that matter, constructed wetlands are currently acknowledged as an efficient wastewater treatment solution. Constructed wetlands consume less material and energy, are cheap to implement, do not generate sludge, and maintain unskilled workers. However, in many parts of the world

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where constructed wetlands have widely been using these practices has been ignored in most of developing country even though it provides effective and low-cost wastewater treatment [11].

On the contrary, from previous research recommends using low-cost wastewater treatment for water reclaimed. A study by Galkina &Vasyutina [12] argues that using the wastewater for reuse is not feasible. The wastewater deems not possible due to uncertainty about its water quality and sanitary level. The author emphasizes that traditional methods like sedimentation and waste separation of water treatment for reuse are insufficient to ensure quality. Therefore, the authors suggest using rainwater to replace 50% of water usage. Rainwater does not require additional treatment; it requires installing a primary filter into storage tanks. In comparison, rainwater is undisputedly less pollutant and high sanitary level compared to wastewater. The use of rainwater for recycling is not doable in the long run. It was constrained to rain itself. It needed steady rain to supply enough water for daily usage, especially in an industry that requires a large amount of water to operate. Moreover, some countries may have less or no rain throughout the year. Although using rainwater is not a bad practice, implementing both rainwater harvesting and reusing treated wastewater could further save more water resources as a whole. The challenge of implementing an effective reclaimed system based on studies is creating innovative and integrated technologies that are low-cost and environmentally friendly.

4. Hydraulic model for the water distribution network

A water supply system is a collection of engineered hydrologic and hydraulic components that deliver water for home, industrial, and firefighting uses, amongst many others uses. The water distribution system composes of intake structures, treatment units, and storage tanks [13]. Research has investigated this on hydraulic modelling of a water distribution network in a vacation area with highly variable characteristics using Supervisory Control and Data Acquisition SCADA. The purpose of this study is to recommend a viable modelling strategy for defining nodal water demands in order to improve the performance of hydraulic models. Using trial and error method the model calibration study was conducted using Hazen – Williams (HW) and pipe roughness coefficient. Hazen-William's equation, depend only on a single factor called the capacity factor (C) which relies on the pipe material and age, where it varies on the surface of a different type of pipe. The recommended value of the H-W roughness coefficient (C) is found as 60 for all pressure measurement points (PMP), giving the minimum model prediction error. The result showed a difference in velocity where pilot study area PSA are low compared to simulation model. Based on the observation the PSA network pipes are aging and relatively old. Deposition particles in pipes decrease the diameter of water flowing and rougher surfaces decrease velocity. Minor losses are incorporated into PSA due to the extensive network of service pipe connections, valves, pipe fittings, bends, and street junctions [14]. Therefore, for future studies it is importance to observe the current condition of the water distribution network in order to produce verification model and reducing unnecessary error during hydraulic modelling.

Further research on one method employed base on Nagpur's water distribution system, modelling and optimization study had been conducted using both Water Geospatial Engineering Modelling System WaterGEMS and EPANET. The study's objectives are to demonstrate the necessity for simplified yet sufficiently accurate models that properly simulate the complex and nonlinear structure of water distribution systems to improve their performance. EPANET simulates the water movement and quality behaviour within pressurized pipe networks over a lengthy period. Pipe networks are made up of pipes, nodes (interconnections), pumps, valves, and storage tanks or reservoirs. Meanwhile, WaterGEMS can identify prospective issue locations, accommodate service area expansion, and plan capital enhancements effectively. When system development is projected, the capacity of the water network to serve its consumers adequately is considered. Frictional head loss occurs across the length of a pipe due to the viscosity of the fluid and the turbulence of the flow. Both modes were tested for stability. Based on the result compared there is a slight difference between the outcomes provided by these two software programs [15]. Further detailed design and modelling are necessary; the scope of the study only included comparing EPANET and WaterGEMS results and optimizing the distribution system.

A similar technique was used to identify critical locations throughout the current water distribution system. Water GEMS software was used to generate the hydraulic model. A color-coding scheme for several pressure head ranges at the connections is created before obtaining the results. Insufficient pressures at some distribution network connections develop as a result of pipe inadequacy. Appropriate pressures can be attained by installing parallel pipes of equal diameter or by substituting a larger diameter pipe [16]. Replacing aging pipelines would affect customers by disrupting water supply and increasing expenditures. Certain modelling limitations may arise due to inaccurate input data, the pipe's C value, and unaccounted population.

Similarly, some writers have proposed that the study and application of LOOP 4.0 and Water GEMS V8i software be used to design and analyse the water conveying system to ensure adequate water supply amount and pressure [17]. The LOOP 4.0 software is freely accessible and compared the results to those obtained using Water Gems v8i. Water Gems v8i is a computer program that simulates pressurized pipe networks' hydraulic and water quality behaviour using EPS (extended period simulation). Frictional head loss occurs across the length of a pipe due to the viscosity of the fluid and the turbulence of the flow. Both modes were tested for stability. There is a slight difference between the outcomes provided by these two software programs. It is discovered that using the LOOP 4.0 software results in the most cost-effective design of the water supply network in terms of the overall cost of the pipes. The design control parameters in LOOP software are maximum and minimum head loss constraint. Whereas in Water Gems software, design control parameters are maximum and minimum velocity limitations are considered. However, the analysis makes no consideration for leaks and bursts due to pressure loss, as leakage losses cannot be estimated in software. As a result, it can be concluded that hydraulic modelling software such as EPANET, WaterGEMS, and LOOP 4.0 have a lot in common when running simulations on water distribution networks. The challenges of running an accurate hydraulic model simulation are data accuracy, design, the current condition of water distribution network, time constraint, software availability, and desired output. For the most cost-effective plan, use LOOP 4.0 software, while EPANET is good on simulating water movement and quality within the pressurized pipes and WaterGEMS could provide both features with a more effective program at the same time, it is expensive.

5. Geographic information system

GIS model applications in water supply systems are to generate intricate details of the water supply system through the use of a GIS model by creating an alphanumeric database. The network's elements are transferred into a GIS context using ArcMap to assist in integrating, interpreting, and simulation. The GIS models use several programs to identify structural and functional issues, forecast operating scenarios, and simulate water supply system components. GIS models generate digital maps and reports that can aid administrative authorities on the water distribution network allowing more effective management to convey the water to consumers [18]. GIS concepts and technologies are critical in data gathering and preservation, condition evaluation via visualization and modeling, and message transmission. Rehabilitating, refurbishing, updating, and automating a water supply system improves its effectiveness. For studies GIS methods for monitoring water supply systems must be enhanced by linking various information and modernizing work schedules.

A similar study, GIS Mapping of water supply, is conducted on urban Slums. To develop a water distribution system using GIS and provide sufficient potable water in the needed volumes and quality to slum communities. The initial work is used to prepare GIS datasets base on ground control points using Chittagong Water Supply and Sewerage Authority CWASA coordinate system and the satellite imagery. Spatial adjustment to correct for significant errors. Water supply are scarce to the urban poor due to the city's unfairness in water distribution related to image. The residents of slum areas suffer from various ailments, including skin infections, as a result of the poor-quality water supply provided. Other factor of water supply, quality, and distribution need to be considered for additional research [19].

More research on developing a GIS-based water management system is conducted on the Achara water distribution network layout at Enugu, Enugu State, Nigeria. The study was conducted to create a system that will aid in the improvement of service delivery and infrastructure upkeep and to develop a visual representation of the existing water delivery network. The result show that a the half of study area has not been covered by water supply network and some pipes are not functioning properly [20]. Therefore, a new database is developed to solve the water supply coverage problem. The developed database will aid in the improvement works. Additionally, it will enable efficient and rapid fault tracking, enhancing user satisfaction. Based on the studies that have been carried out, most suggest including additional information and factors that might affect the water supply for GIS to understand and develop a better working water distribution system, especially for non-potable purposes. The water quality assessment is essential in creating a water distribution system for reclaimed water. The treated wastewater is not fully clean as potable water and is bound to have impurities. This factor is to be taken into consideration for reclaimed water distribution network development.

6. Conclusion

In conclusion, increased water demand, combined with population growth, water scarcity, climate change, and rapid economic growth, further push use of reclaimed water in industries as an alternative to replace freshwater for non-potable use. Therefore, an effective water distribution system network should be identified to establish links for incorporating water reclamation into urban and industrial planning. This can be helped by employing hydraulic modeling and incorporating GIS to analyze, manage, and develop the water distribution network based on growing supply-demand. Hydraulic modeling use to compute and analyze the water supply demand for a certain period based on daily water use. It also determines the suitable parameter for the pipeline to deliver an adequate amount of pressure for water to reach the consumer efficiently. The developed hydraulic model was then integrated into GIS for network layout and visualization of the water distribution system. Parallel to the technical challenges, the feasibility of amending existing legislation or enacting new policies as well as financial structure to support water reclamation effort. Nonetheless attention should be paid to the public and stakeholder involvement to determine the level of acceptance for water reclamation for industrial purposes and the incorporation of water reclamation options into integrated water and sanitation infrastructure planning. These factors will eventually result in increased water availability for domestic and industrial use, thereby increasing the likelihood of economic growth and urban health and well-being growth in the future.

This review paper hopefully could provide direction for further studies by investigating the climate change and uncertainties on forecasting water supply and demand. In addition, overcoming the challenge of implementing an effective reclaimed system by creating innovative and integrated technologies that are low-cost and environmentally friendly. Lastly, further future studies in GIS need to assess the water quality for monitoring and keeping in check the sanitary level of water conveyed to avoid any contaminant and pollutant and provide countermeasures if necessary.

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