بسم الله الرحمن الرحيم

Sudan University of Science and Technology

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Assessment of the Effectiveness of Blue Nile and White Nile Water Treatment Plants in Khartoum State

(A Case Study of Bahri, Mogran, Alshajara and Jabal Awlia Plants)

تقييم فعالية محطات معالجة المياه على النيل الأزرق والأبيض بولاية الخرطوم

(دراسة حالة محطات بحري و المقرن و الشجرة وجبل أولياء)

A thesis Submitted in Partial Fulfillment for the Requirements of the Degree of M.Sc. in Environmental Engineering

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بسم الله الرحمن الرحيم

الإستهلال

قال تعالى:

{وَجَعَلْنَا مِنَ الْمَاء كُلَّ شَيْءٍ حَيٍّ أَفَلَا يُؤْمِنُونَ}

صدق الله العظيم
سورة الأنبياء ـ الآية (30)

Dedication

I am dedicating this thesis to beloved people who have meant and continue to mean so much to me. Although they are no longer of this world, their memories continue to regulate my life. First and foremost, to my father whose love for me knew no limit and though his age was short but he left a void which never been filled in our lives. Also I dedicate this to my grandfather who gone forever away from our loving eyes I will never forget you on as long as I shall live .

I am extremely grateful to my eternal cheerleader, my mother which exterminated its youth to sake me By giving me her love, prayers, caring and continuous sacrifices to my educating and preparing me for the future.

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Finally, my thanks go to all the people who have supported me to complete the research work directly or indirectly.

Abstract

Treatment of water is considered as a critical challenge especially in developing countries since this treatment is an essential facility to conserve the public health and environment by eliminating of waterborne diseases and pathogens and make it acceptable to consumers.

The objective of this research is to assess the efficiency of Blue Nile (Bahri and Mogran) and White Nile (Alshajra and Jabal Awlia) water treatment plants which consist to conventional water treatment units such as flocculation, sedimentation, filtration, and disinfection .

Four water treatment plants were investigated in different areas and coordinates. Samples were carefully gathered from the study area (Khartoum state site area) according of approved sampling procedures.

Several characteristics (Turbidity, Total Alkalinity, pH and residual chlorine) of both the raw and treated water were studied according to Standard Methods and Procedures to evaluate the performance and quality of treated water from Water Treatment Plants.

The results show that the treated water from the plants meet specifications in terms of total alkalinity and pH, and often fail to satisfy specifications in terms of residual chlorine and turbidity.

The study recommends to enhance the efficiency of treatment in terms of residual chlorine and turbidity specially during flooding season.

المستخلص

تعتبر معالجة المياه تحدياً حاسماً وخاصة في البلدان النامية، حيث أن هذه المعالجة هي عنصر أساسي للحفاظ على الصحة العامة والبيئة وذلك من خلال القضاء على الأمراض المنقولة عن طريق المياه ومسببات الأمراض وجعلها مقبولة للمستهلكين.

الهدف من هذا البحث هو تقييم فعالية محطات معالجة المياه على النيل الأزرق (بحري والمقرن) والنيل الأبيض (الشجرة وجبل أولياء) والتي تتكون من وحدات معالجة المياه التقليدية مثل التلبد والترسيب والترشيح والتطهير.

تمت الدراسة لأربعة محطات في مختلف المناطق والإحداثيات ومن ثم جمعت العينات بعناية من منطقة الدراسة (ولاية الخرطوم) وفقاً لإجراءات أخذ العينات المعتمدة.

تمت دراسة عدد من الخواص مثل (العكارة، القلوية الكلية، الأس الهيدروجيني، والكلور المتبقي) لكل من المياه الخام والمعالجة وفقاً للطرق والإجراءات القياسية لتقييم أداء وجودة المياه المعالجة من محطات معالجة المياه.

أظهرت النتائج أن المياه المعالجة من المحطات تفي بالمواصفات من القلوية الكلية ودرجة الحموضة، وغالباً ما تفشل في تلبية المواصفات من حيث الكلور المتبقي و العكارة.

توصي الدراسة بتحسين كفاءة المعالجة من حيث الكلور المتبقي والعكارة خصوصاً خلال فترة الفيضان.

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INTRODUCTION

1.1 General

Water is a transparent liquid that is colorless, odorless and tasteless. It consists of two hydrogen atoms and one atom of oxygen [1].The oxygen atoms carry a negative charge, and hydrogen atoms carry a positive charge. The water molecule (H_2O) is an excellent solvent for many ionic compounds [2].Water is found on the earth as liquid, gas and solid. Water in liquid state Molecules are close together with weak bonds. When the water boils at 100°C, it turns into steam, and its particles move apart. Water becomes solid when frozen at 0°C .Water has many unique properties that make it very important where we cannot live without water. About 70 per cent of the human body is water. It fills and surrounds the cells of the body. Helps to transport nutrients all over your body, control body temperature, get rid of waste, digest food, and soften joints. Water is not only important for man, but for all life on Earth. Provides habitats for living organisms where they live within and around them. The plant also feeds on water are used in many industries for treatment and cooling. Water is also necessary for transporting goods and used for the extraction and refining of natural resources. is used to irrigate agricultural land [3]. We rely on pure water in almost every aspect of our lives. We depend on them for drinking, bathing, cooking, swimming, fishing and boating. We count on it to cultivate and treat our food and feed plants and animals. We also need to entertain [4].Water is a precious natural resource that must be protected and preserved. Clean water is not only important for use in homes and society, but is necessary to maintain a natural ecological balance where several types of wildlife live in and around water bodies. Therefore, water bodies must be clean and protected from pollution sources such as oil, radioactive waste, chemical and garbage [3]. The total volume of water in the world reaches 1.338.000 km^3[2]. The oceans contain 97% of the total water in the biosphere, about 2% of fresh water, but most of it is linked to ice and glaciers, 1% were found in lakes and rivers. There is only a tiny amount in the atmosphere[5]. Increased water consumption affects water supply and water scarcity occurs if there is insufficient water to meet natural human needs. Water availability depends on water sources. Surface water is the water on the surface of the earth lakes, rivers, waterways, reservoirs and wetlands [3]. Groundwater the water falls as precipitation and is influenced by soil and organisms at or near the surface as groundwater in the saturated zone. Water is recharged by fresh water from the surface[7]. Sea water was obtained through desalination. Desalination is done in several ways such as distillation, reverse osmosis, electric washing, and ion exchange. Reclaimed water and reuse of wastewater treatment used for irrigation, landscaping, ground water recharge, indirect portable water, etc. [6].Surface water and groundwater are often treated as separate entities. However, most surface water is in constant interaction with groundwater. In few cases there is no interaction between them. Surface waterways often acquire water from underground water systems. Sometimes the reverse is true, and the groundwater is replenished by leakage from the current flow channels (and / or flooded flood plains); in these cases, the withdrawal of water from the streams reduces recharge to groundwater [8].On Some ground water is found holes in the earth's surface and emerges in the form of freshwater springs. Over time, water returns to the ocean, where the hydrological cycle begins [9]. The purpose of water treatment is to provide safe drinking water that does not contain any taste, odor or color; and to provide sufficient quantities of water to meet domestic, commercial, industrial and fire protection needs. All water produced by public water systems must be drinkable, although only about 1% of the water produced is used for drinking and cooking [1]. Drinking water comes either from ground water or surface water. We should usually spend a lot of time, effort and money to make sure drinking water is free of pollution. We often obtain high-quality drinking water from groundwater sources because these sources are protected from surface pollution by the soil layer above them. However, it may contain high concentrations of minerals; some of the metals found in rocks and soil melt in water. Since drinking water from groundwater sources is generally of high quality, water suppliers may only need to purge water before being connected and used by the public. In rare cases, the ocean is used after salt is removed using desalination equipment. Surface water is usually easier to collect and treat than groundwater. Surface water must be treated and purified prior to distribution to the public, because surface water sources are more susceptible to pollution than activities on the surface. Water treatment is the process of improving water quality in accordance with water quality standards to be suitable for the intended use of water.

1.2 Statement of the problem:

Water is the foundation of life. Many areas in Khartoum state suffer from water scarcity despite the presence of the Nile River. We also notice the presence of turbidity in tap water in domestic water in several areas of Khartoum State.

1.3 Objectives:

1.3.1 General objective:

To evaluate the performance for water treatment plants located at Blue Nile and White Nile at Khartoum state.

1.3.2 Specific objectives

- To investigate performance for water treatment plants.
- To assess quality of treated water (Turbidity, total alkalinity and residual chlorine).
- To check the compliance and agreement range of water treatment performance with the specifications.

1.4 Justification of study

Evaluate the efficiency of some drinking water plants in Khartoum State. And know extent of their conformity with Sudanese specifications in terms of turbidity, pH, total alkalinity and the residual chlorine percentage. And the coverage of these plants to the areas that feed on them.

1.5 Questions and Hypothesis:

What is the capacity of each plant?

What areas feed from these plants?

What are the treatment steps in each plant?

Is the treated water satisfying the Sudanese specifications in terms of the turbidity, pH, Total Alkalinity, and residual chlorine?

1.6 Time limitations:

From 1/6/2018 to 30/1/2019.

CHAPTER TWO

CHAPTER TWO

LITERATURE REVIEW

2.1 Sources of Water

Water in our planet is available in the oceans, in the atmosphere, as well as on and under the land surface. The transport of water between these reservoirs in various phases plays a central role in the Earth's climate. Water evaporates from the oceans and the land surface into the atmosphere, where it is a devoted across the face of the Earth in the form of water vapor. Eventually, this water vapor condenses within clouds and precipitates in the forms of rain, snow, sleet, or hail back to the Earth's surface. This precipitation can fall on open bodies of water, be intercepted and transpired by vegetation, and become surface runoff and/or recharge groundwater. Water that infiltrates into the ground surface can percolate into deeper zones to become a part of groundwater storage to eventually reappear as stream flow or become mixed with saline groundwater in coastal zones. In this final step, water re-enters the ocean from which it will eventually evaporate again, completing the hydrological cycle[10]. As shown in figure (2.1).

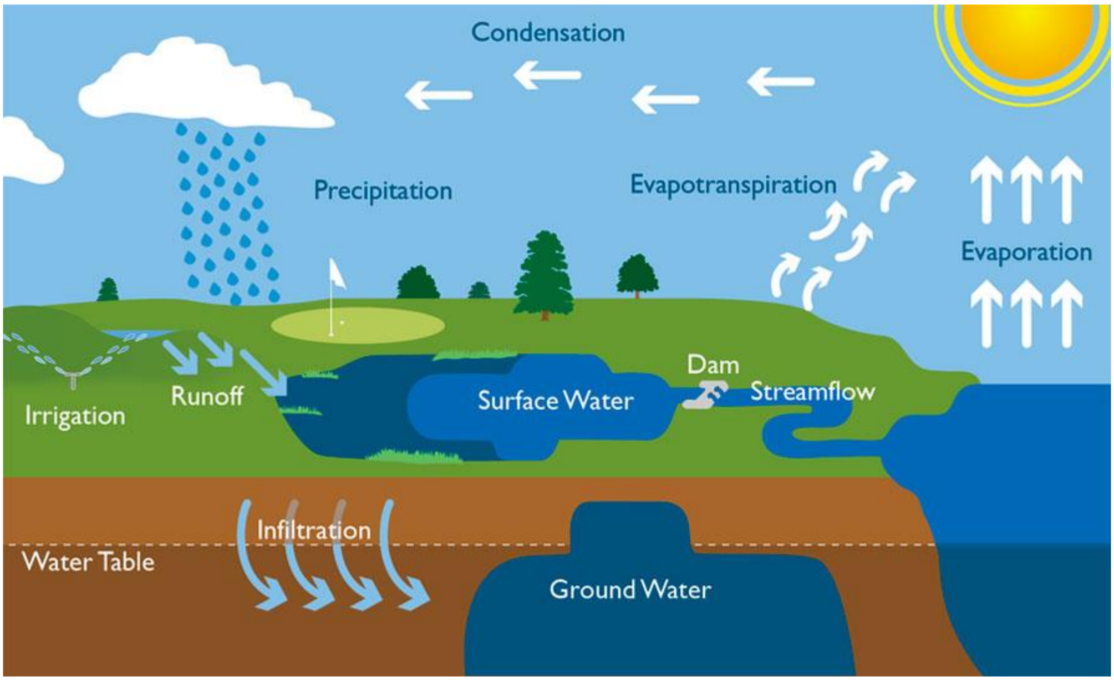

Fig (2.1): hydrological cycle [11]

The hydrological cycle has a great deal of variability in time and space. Precipitation, which is the source of virtually all freshwater in the hydrological cycle, falls nearly everywhere, but its distribution, is highly variable. Similarly, evaporation and transpiration return water to the atmosphere nearly everywhere, but evaporation and transpiration rates vary considerably according to climatic conditions [12].

The main processes involved in the hydrologic cycle are evaporation, precipitation, interception, and infiltration, and seepage, storage in various water bodies, runoff and transpiration. [13]

- **Evaporation:**
  Water left standing in the open will be sucked up by the air as water vapor. This is called evaporation. The rate at which water evaporates depends on the dryness of the air, the temperature of the ambient air and water, the amount of water exposed (the surface area), and the amount of air movement (wind
  Precipitation is the fall of solid or liquid water over land and oceans, and is the major driver of the hydrologic cycle over land. Hydrologists have traditionally recognized precipitation as the start of the hydrologic cycle because all other hydrologic phenomena (e.g., evaporation, runoff, recharge) result from it. The importance of speed)[14].
- **Precipitation:**
  precipitation to the hydrologic cycle cannot be overstated [10]**.**
- **Infiltration:**
  Movement of water is into and through soil [15]**.**
- **Runoff:**
  Runoff is the transport of liquid water across the surface of the Earth. Excess water in saturated soils flows into rivers to the ocean, to terminal lakes or swamps. Groundwater can interact with stream flow in rivers if the water table is near the surface [14].
- **Evapotranspiration:**
  Water returned to the atmosphere by evaporation from water and land surfaces, and by the activity of living plants [15].

2.1.1 Surface water

Surface water is water that is open to the atmosphere and results from overland flow it is also said to be the result of surface runoff. [13] Examples of Surface Water Specific sources that are classified as surface water include the following:

a) Rivers and streams:

Rivers and streams represent a good source of water. Streams tend to vary more in flow rates, helping shed immediate rainfall, whereas rivers typically display a delayed runoff of rain and are fed by a seasonal release of water locked in snow caps or glaciers.

b) **Lakes and ponds:**

The flow of water in a river or stream may be temporarily interrupted by large depressions in the ground which must be filled before the journey is again resumed. If it's a big depression, we call it a lake; a smaller one is simply a pond [14].

c) Ocean:

This vast body of salt water covers 70% of the Earth's surface it stores and circulates enormous amounts of water and energy. In addition, patterns of ocean surface temperatures can exert a strong influence on circulation patterns in the atmosphere. Frequently, the ocean is divided into two parts, an upper and lower zone. The upper zone is considerably warmer and less saline than the lower zone, and the two are separated by a relatively sharp thermo cline [10].

d) **Man-made impoundments**:

(Lakes made by damming a stream or river) [16] Damming one of these sluices is, in effect, a means of rainfall collection. Another crude but inexpensive way to duplicate this effect is to dig a trench across a slope in the path of runoff, terminating the lower side in some type of storage[14].There are both advantages and disadvantages to surface water: The primary advantages to using surface water as a water source includes it are easily located [17] is generally softer than groundwater, which makes treatment much simpler. The most common disadvantages Surface water collects a wide variety of contaminants and microorganisms that cause waterborne diseases [18, 17]. The turbidity of a surface water source often fluctuates with the amount of precipitation. The temperature of surface water fluctuates with the ambient temperature. The intake structure may become clogged or damaged from winter ice, or the source may be so shallow that it completely freezes in the winter. This is a common problem with surface water sources in the arctic [17].

2.1.2 Groundwater

Groundwater is water that exists in the pore spaces between sand, gravel, and rocks in the earth and can be brought to the surface using wells.[19] Beneath the earth ' s surface, water resides in two general zones: the saturated zone and the unsaturated zone. The area where water fills cracks and spaces in soil, sand, and rocks is called the saturated zone. Groundwater refers to the water in the saturated zone. The top of this zone is called the water table. The unsaturated zone lies between the water table and the land surface [20]. Groundwater is fresh water located in the subsurface pore space of soil and rocks. [16] The Environmental Protection Agency has classified all groundwater as drinking water unless it is specifically exempted and, as such, must meet the applicable discharge and cleanup standards [21].Includes all water obtained from dug, drilled, bored or driven wells, and infiltration lines [22].Groundwater is obtained from Wells, springs that are not influenced by surface water or a local hydrologic event [17].Groundwater is by far the largest freshwater resource of the globe. On a global scale, 97 per cent of the freshwater reserve is stored in aquifers. Fresh groundwater constitutes about 30 per cent of the total Freshwater resources [23].Aquifers may be confined or unconfined

.A confined aquifer is overlain by an impermeable layer that prevents recharge (and contamination) by rainfall or surface water. Recharge of confined aquifers occurs where the permeable rock outcrops at or near the surface, which may be some distance from the area of exploitation. This feature may make control of quality and of pollution more difficult. Some aquifers are not perfectly confined and are termed semi-confined or leaky [24].May receives water from both outcrop areas and overlying aquifers. Delineating the aquifer protection area can be extensive and complex [15].Unconfined aquifers are overlain by a permeable, unsaturated zone that allows surface water to percolate down to the water table. Consequently, they are generally recharged over a wide area and are often shallow with a tendency for interaction with surface water [24].The biggest risk to an unconfined aquifer is the water, potentially carrying contaminants, moving through the permeable materials directly above it [15].There are both advantages and disadvantages to groundwater: The advantages of Groundwater are not as easily contaminated. The quality of groundwater, while not always as good as would be preferred, is stable throughout the year. Groundwater sources are generally lower in bacteriological count. Disadvantages of groundwater once a groundwater source is contaminated, it is difficult for it to recover. There is no easy way to remove the contaminants. Groundwater usually contains more minerals, including increased levels of hardness because groundwater is in contact longer with minerals; there is more time to bring them into solution. Removal of groundwater normally requires a pump, thus increasing operation cost .Groundwater is more susceptible to long-term contamination from fuel spills. Groundwater supplies often have high levels of iron and manganese, thus increasing treatment cost. Wells in the coastal areas are subject to salt water intrusion into the aquifer and well. This contamination is difficult to predict and costly to treat and Sources of contamination can be hidden from sight [17].Groundwater is vulnerable to pollution. Contamination occurs when pollutants become dissolved in water at the land surface and are carried down to the aquifer with the water. Groundwater quality can be adversely affected by human activities and natural processes. Except where contaminated water is injected directly into an aquifer, essentially all groundwater pollutants enter with water from the land surface [20]. Natural processes include result from dissolution caused by long-term contact between the water and the rocks and minerals. Some natural constituents that might need to be removed by water treatment include Iron and manganese ,Hardness, Trace inorganic, Salinity, Natural organic matter[19] Human contributions can come in polluting groundwater by Gas stations store gasoline in underground tanks, which can corrode, leak, and contaminate groundwater, Improperly constructed septic systems can leak nitrate, household chemicals, and other contaminants , discharging chemical wastes on the ground, in landfills, in open pits, or into waste disposal wells have contaminated water supplies with many kinds of industrial chemicals. and During irrigation, plants uptake some water but excess water can percolate downward and reach the underlying groundwater table. Pesticides, herbicides, and fertilizers applied to the land can travel down with the water and contaminate the groundwater [19, 20].

2.1.3 Groundwater under the direct influence of surface water (GUDISW)

Is the water produced when a well or spring (groundwater) is affected by a source of nearby surface water or by a local hydrological event [17].

2.2 Water treatment:

Water is important natural resource of the Earth and essential for the existence of all living things. The intimate relationship between the human society and water is symbolized by the fact that almost all ancient civilizations originated on the banks of large rivers. In the present, water is still an essential natural resource for keeping the health and pleasant lives of people, and for making valuable natural and industrial products [25].natural Water cannot be consumed in its natural state due to possible presence of Floating objects, Algae, Excessive Fe, Mn or Hardness, Suspended Solids, Dissolved gases Taste, Odor or Color, Organic or bacteriological pollution [26].Those substances in water cause various problems in systems using water. In the case of drinking water, suspended solids and microorganisms must give a bad influence on the human health. In cooling water systems and boiler systems, hard soluble matter, such as calcium carbonate, may deposit as a scale on the heat transfer surfaces of heat exchangers and boilers. Then their thermal efficiencies are reduced by the scaling. Dissolved oxygen causes the corrosion of metals composed of those systems and shortens their service lives. Microorganisms may grow and form slime (biofouling) on heat exchanger tube surfaces, etc.The slime adhesion reduces the thermal efficiencies of heat exchangers and sometimes causes an under deposit corrosion or microbiologically influenced corrosion (MIC) of metals. Even when water of same quality is used, the kinds and the degrees of problems caused by water vary depending on the usages of water and the operational conditions of systems .Drinking water should be suitable for human consumption and for all usual domestic purposes [27]. Water treatment is changes or alters the chemical, physical, and bacteriological quality of water [28]. The term conventional water treatment refers to the treatment of water from a surface water source by a series of processes aimed at removing suspended and colloidal material from the water, disinfecting the water, and stabilizing the water chemically. Conventional treatment of water for domestic use involves a number of treatment steps aimed at achieving the following objectives: Removal of suspended and colloidal matter to an acceptable level by means of coagulation-flocculation, sedimentation, sand filtration and Disinfection to produce water that is safe to drink Chemical stabilization of the water to prevent corrosion of pipelines, attack on concrete pipes and structures or the formation of chemical scale in distribution systems and fixtures The conventional treatment methods for removal of suspended and colloidal material from water include chemical coagulation of small colloidal particles, flocculation of the small particles to form larger flocs or aggregates, followed by sedimentation and sand filtration. When the water contains a large amount of suspended material, larger suspended particles such as sand particles can be removed by means of settling without coagulation and flocculation. Other methods that can be used include slow sand filtration, flotation, micro-filtration and ultra-filtration [1].Objectives of Treatment to protect the consumer health (bacteriological safe), Make it acceptable by the consumers (aesthetic sight, taste, odor and color), Economical reasons for preventing scaling and corrosion in pipe lines and stain in cloths durin laundering and In some cases need to make up deficiency in some quality in water [29].Choice of treatment process depends on Quality of raw water (Water source, period of design year), Required quality of treated water (end use) and Economic resources available of O&M [26]. the amount of suspended solids, the turbidity of the water, the nature of the suspended material, the chemical properties of the water (alkalinity and pH), the volume of water to be treated, and the availability of facilities, trained operators and supervisors [1]. A Water Treatment Plant aims to ensure that water is Safe for human consumption, Pleasant to consumers and provided at a reasonable cost [30].

2.2.1Surface water treatment:

2.2.1.1 Intakes:

Intakes are structures built in a body of water for the purpose of drawing water for human use. Intake systems include the facilities required to divert and transport water from a supply source, such as a river, lake, or reservoir, to a shore well or pumping station [31].Intake systems can be generally divided into two categories: exposed intakes and submerged intakes [31, 1].Large projects utilise tower like intakes that can be an integral part of the dam or can be a separate structure [1].

2.2.1.2 Flow measurement:

Flow measurement of raw water and finished water is essential for plant operation, process control, water loss control, and billing and because chemical dosing is directly related to raw water flow [1, 32].Flow of water through pipes under pressure is measured by mechanical or differential head losses, such as Venturi meters, flow nozzles or orifice meters. Flow through an open channel is measured by a weir or a venturi-type flume such as the Parshall flume. [1]

2.2.1.3 Screens:

Screening (removes relatively large floating and suspended debris) [33].Objective of screen is removal of coarse solids (pieces of woods, plastics, papers, rags, leaves, roots, etc.), to Protection of pump, valves, pipe line, impellers Classification of screen Based on Opening size to Coarse, Medium, Fine [26].Coarse screens, often termed bar screens or racks, must be provided to intercept large, suspended or floating material. Such screens or racks are made of l/2-inch to 3/4-inch metal Bars spaced to provide 1- to 3-inch openings. and Fine screens Surface waters require screens or strainers for removal of material too small to be intercepted by the coarse rack, These may be basket-type, in-line strainers, manually or hydraulically cleaned by backwashing, or of the traveling type, which are Cleaned by water jets. Fine screen, clear openings should be approximately 3/8 inch. The velocity of the water in the screen openings should be less than 2 feet per second at maximum design flow through the screen and minimum screen submergence [34].screen classified by Configuration to bar screens and Mesh screens. Also classified by Cleaning Method to Manual, Mechanical, Raked, Water jet. Classified by Screen surface: Fixed, Moving [26].

2.2.1.4 Aeration:

Also known as air stripping, mixes air with water to volatilize contaminants (turn them to vapor) [35].Oxygenation is one of the purposes of aeration. Others are removal of volatile organic substances, hydrogen sulfide, ammonia, and volatile organic compounds [36, 33].A gas or substance dissolved in water may further react with water. Such a reaction is called hydration [36].Examples of simple aerators include: A system that cascades the water or passes it through a slotted container, A system that runs water over a corrugated surface and An airlift pump that introduces oxygen as water is drawn from a well other aeration systems that might be suable for small systems include packed column aeration, diffused aeration, and multiple tray aeration. Emerging technologies that use aeration for organics removal include mechanical aeration, catenary grid, and Higee aeration [35].Aeration depends on water temperature, gas type and its solubility in water [33].

2.2.1.5 Oxidation:

Chemical oxidation is used in water treatment to aid in the removal of inorganic contaminants such as iron (Fe^{2+}), manganese (Mn^{2+}), and arsenic (As^{3+}) to improve removals of particles by coagulation or to destroy taste- and odor-causing compounds. Oxidation can also be used prior to coagulation, filtration, adsorption, or sedimentation to improve the removal of in organics, particulates, taste, or odor. Oxidants The most commonly used oxidants in small systems include chlorine (Cl_2) and potassium permanganate ($KMnO_4$). To a lesser extent, ozone and chlorine dioxide are also used for this purpose. Chlorine is supplied in gas, solid, and liquid forms; and potassium permanganate is usually supplied as a fine granular solid material that is dissolved in water. Ozone is a gas that is generated onsite using pure oxygen or air. The selection of the most desirable oxidant is dependent upon a number of factors, including process requirements, operational cost, chemical safety, and operational complexity [16].

2.2.1.6 Simple Settling or Pre Sedimentation:

Simple settling of water is often used as a pretreatment step to remove larger suspended particles from water without coagulation and flocculation [1]. The process removes relatively high concentrations of easily settled solids (e.g., sand and silt). By allowing adequate detention time in the basin, coarser and other easily settle able particles drop out of the water sources. After settling of the particles clear water can be decanted from the container. Settling can be performed as a batch process (filling a tank with the water, allowing sufficient time for settling, and decanting of the clear water) or as a continuous process. In a continuous process the water flows through the reservoir at a slow rate that allows time for settling while clarified water is withdrawn continuously [18].

2.2.1.7 Coagulation:

Coagulation is the process by means of which the colloidal particles in water are destabilized (i.e. a change the nature of the colloidal material in the water to facilitate its removal)[38].particles in water carry the same charges, and repulsion prevents them from combining into larger particulates to settle. Thus, some chemical and physical techniques are applied to help them settle [36]. Coagulants are inorganic salts added to water to remove the bulk suspended solids and other various contaminants and reduces the time required to settle it and neutralize the electrostatic charges on particles , remove fine particles. The otherwise very difficult to remove coagulation can also be effective in removing many protozoa, bacteria and viruses. and initiate coagulation [39,3,40] chemicals used in coagulation are Alum—$Al_2(SO_4)_3 \cdot 14\ (H_2O)$, Poly aluminum chloride(PAC) and Ferric chloride—$FeCl_3$.[31] The efficiency of the coagulation process depends on the raw water properties, the coagulant used and operational factors including mixing conditions, temperature, coagulant dose rate and pH value [3].

2.2.1.8 Rapid mixing:

Rapid mixing (sometimes called “flash mixing”) [33] Oxidants are injected as a gas or a liquid. Mixing or diffusion of the gas or liquid into the water stream occurs very quickly [16]. Essentially is necessary to distribute the coagulant species among the particles in as short a time as possible. Rapid mixing needs to be intense but of short duration (no more than a few seconds). Otherwise, the nature of flocs formed subsequently can be affected. Prolonged periods of intense mixing can lead to the growth of small, compact flocs that grow slowly when the shear rate is reduced [33].

2.2.1.9 Slow mixing:

process helps uniform distribution of the coagulant and colloidal particles in the water which leads to floc [41].The stirring should be gentle and can be achieved through baffled mixing, mechanical mixing and air agitation [42, 43]. Insufficient mixing will result in ineffective collisions and poor floc formation. And Excessive mixing may tear apart or shear the floc that has been formed. the detention time Required for the necessary chemical reactions to take place Minimum 30 minutes with 45 minutes recommended [8,44].Basic information should be known when designing flocculation basins are optimum velocity gradients, flocculation time, optimum energy input or taper of energy input during flocculation [45].

2.2.1.10 Sedimentation:

Sedimentation is the process in which the aggregates that have been formed during coagulation and flocculation are allowed to settle from the water. The flocs collect as sludge at the bottom of the sedimentation tank from where it must be removed on a regular basis. The flocs settle to the bottom of the tank and the clean water leaves the sedimentation tank through collection troughs located at the top of the tank [44]. Solids settle based on their gravitational force (with and without externally added chemicals) [18]. Sedimentation is used to remove a large percentage of the solids from the water, thereby improving subsequent filter performance [29]. The amount of floc that settles out of the water is dependent on the time and depth of the basin. Normally detention time for settling basin is 2 to 4 hours [42]. During storage, about 90% of suspended solids settle down within 24 hours and water become clear and clean and certain heavier chemicals also settle down during storage [46].The sedimentation basin is cleaned by dredging and / or removing the sediment from the basin[47].Different designs exist for sedimentation tanks. The most common designs are rectangular horizontal flow tanks in which the water enters one side and leaves at the other end. (Flow is in one direction, parallel to the basin length, called rectilinear flow) High tolerance to changing water conditions [44].this type is normally used at large conventional treatment works. Circular tanks with flat or cone shaped bottoms are also used, especially at smaller works. Flocculated water enters the tank at a central distribution section and clarified water leaves the tank at collection troughs at the circumference of the tank.[1] Settling depend on solid physical characteristics (diameter, density) and medium temperature, viscosity, density [18]. Figure (2.2) and Figure (2.3) show Circular and Rectangular settling tank respectively.

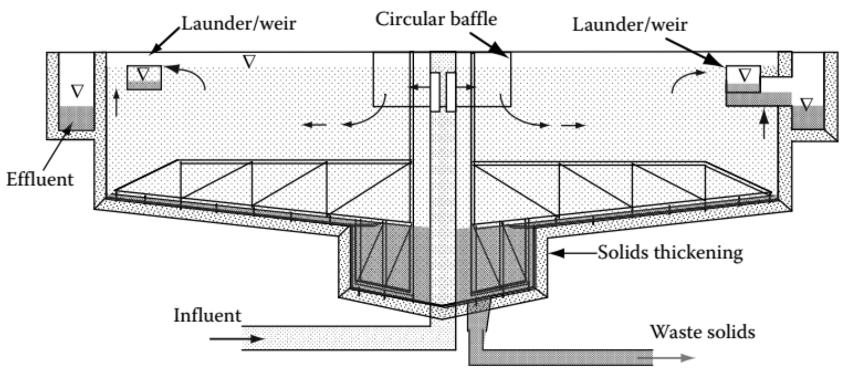

Fig (2.2): Circular settling basin [48].

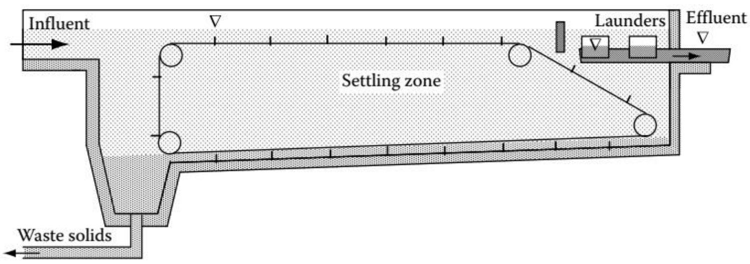

Fig (2.3): Rectangular settling basin [48].

2.2.1.11 Flotation:

is an effective process for removal of relatively light types of flocs. Flotation involves the formation of small air bubbles in water that has to be flocculated. The bubbles attach to the flocs causing them to rise to the surface where they are collected as a froth that is removed from the top of the flotation unit. Air is dissolved under pressure in a small amount of water in a device called a saturator. This water that is saturated with dissolved air is added to the main stream of water that is to be treated. When the pressure is released after the saturated water is mixed with the water to be treated, the dissolved air comes out of solution in the form of very fine bubbles [38].

2.2.1.12 Filtration:

Is the process of removing solids from a fluid by passing it)through a porous medium. The filter media are artificial membranes, nets, sand filter, and high technological filter systems [36].The common types of filter used in water purification are biological or slow sand filter or rapid sand filter that have fairly high flow rates and require relatively little space to operate [27].Pressure filters are modern filters which are used to remove iron and manganese especially better for ground water [49].The choice of filters depends on the required filtering speed and the cleanness requirement. The process of removing the clogged portion of the filter bed by reversing the flow through the bed and washing out the solid is called back washing [36].The types of filters used in WTPs include the following:

a) Rapid sand filtration:

Rapid sand filters are most commonly used to remove floc from coagulated waters. They may also be used to remove turbidity, algae and iron and manganese from raw waters [3].consists of a bed of sand above several layers of gravel in varying sizes [18]. (size range 0.5 to 1.5 mm) to a depth of between 0.5 and 0.8m [50] as shown in figure (2.4). The water flows downwards and solids become concentrated in the upper layers of the bed. Treated water is collected via nozzles in the floor of the filter. The accumulated solids are removed periodically by backwashing with treated water, usually preceded by scouring of the media with air. Frequency of backwashing depends on loading rate and raw water quality and is typically every 24 hours. Backwashing can be initiated automatically after a predetermined head loss has been reached or may be carried out manually. It is important to achieve the required bed expansion in order to ensure filters are washing properly, but care must be taken to prevent loss of media with too high flow rates [3]The principal factor in this decision has been the smaller land requirement for rapid sand filters and lower labor costs. However, rapid sand filters do not produce water of the same quality as slow sand filters and a far greater reliance is placed on disinfection to inactivate bacteria. It is also worth noting that rapid sand filters are not effective in removing viruses [41]. Some sand filters are not open to the atmosphere, but operate under pressure [1]. As shown in figure (2.5).

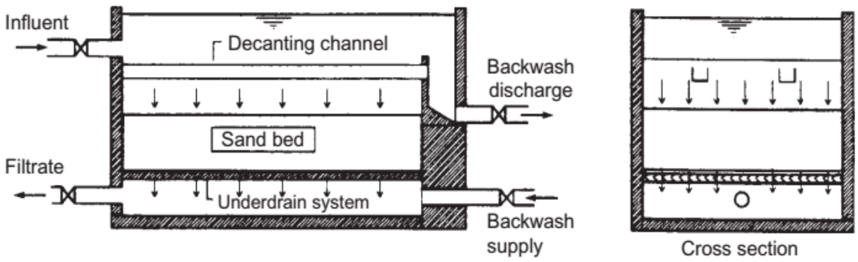

Fig (2.4): Rapid sand filter [51]

b) Slow sand filtration (SSF):

Slow sand filters, sometimes preceded by micro strainers or coarse filtration, are used to remove turbidity, algae and microorganisms. Slow sand filtration is a simple and reliable process and is therefore often suitable for the treatment of small supplies provided that sufficient land is available [3]. Slow sand filters Fig. (2.5) consists of a bed of fine sand above a gravel layer and under drain system [52].Slow sand filtration uses finer sand than a rapid sand filter, typically 0.35-1.0 mm diameter in a sand bed which is typically about 0.8 1m deep [50].During operation the material that is removed collects in the top layer of sand and as filtration progresses, microorganisms and larger organisms establish in the top layer and this layer performs the actual filtration function. During the use of a SSF the top layer becomes biologically active with different micro-organisms and larger organisms establishing in the top and lower layers of the bed. The removal of suspended and colloidal particles in a SSF is therefore a combination of physical straining and filtration as well as biological degradation processes [6].The rate of filtration in a SSF is much slower (about 1-4 m3/m2/day) [50] than in a rapid sand filter and the SSF is not backwashed at all as is done to clean rapid sand filters. The SSF is operated for extended periods before cleaning, typically 1 month or up to 6 months depending on the raw water quality. Shortly after the start of filtering, a thin layer of slime forms on the surface of the sand. This layer is known as the filter skin or Schmutzdecke and is the most important element of the filter. It consists of a variety of micro-organisms that feed on organic matter and bacteria, and in this way functioning as a comprehensive treatment process and not only as a simple filtration process. After several weeks of operation, the resistance of the filter skin will normally increase to such an extent that the filtration rate reduces to very low levels. At that point the filter has to be regenerated. This can be achieved by scraping off the top layer of sand including the filter skin. This will then expose clean sand on which a new filter skin will develop when water is applied to the filter. The water quality will not be acceptable until the filter skin has developed, which may take a few days.[6]Slow sand filtration process is only suitable where the water source is rather clean river or lake water, or water infiltrated from a riverbed. The source water must be with low turbidity all year around. The average turbidity is preferably lower than 10 NTU [53].The main advantage of SSF is that it is a relatively simple process that does not require high levels of skills and operational control to produce water for domestic use. Under many circumstances chemicals are also not required for treatment. However, it is important to note that final disinfection is required to produce microbiologically safe water [6].

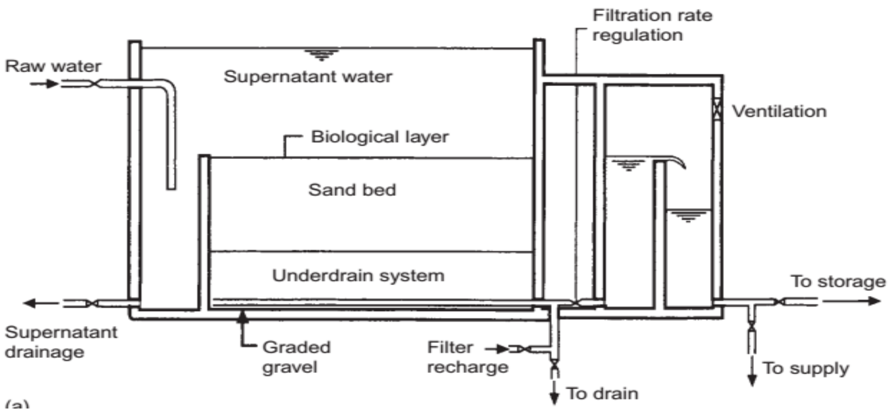

Fig (2.5): Slow sand filter [51]

A comparison between slow sand filters and rapid sand filters is given in table (2.1).

Table 2.1: comparison of important features of slow sand filters and rapid sand filters [54]

parameter	Slow sand filter	Rapid sand filter
Rate of filtration	3 m3/m2 d	125m3/m2/ d
Depth of bed	0.3 m of gravel, 1.2 m of sand reduced to not less than 0.6 m by scraping.	0.5 m of gravel,0.7 m of sand or less, not reduced by washing.

Size of sand	Effective size 0.25 to 0.3 to 0.35 mm, uniformity coefficient 2 to 2 to 3.	0.45mm and higher uniformity co-eff. 1.5 and lower depending on under drainage system.
Grain size distribution of sand in filter	Un stratified	Stratified with smallest or lightest grains at top and coarsest or heaviest at bottom.
Length of run between cleaning	20 to 60 days	12 to 72 hours
Method of cleaning	1-Scrapping off surface layer of sand storing cleaned sand for periodic re-sanding of bed. 2-Washing surface sand in place by washer travelling over sand bed.	Backwashing
Amount of wash water used in cleaning sand	0.2 to 6 % of water filtered	1to 4 to 6% of water filtered
Preparatory treatment of water	Generally none	Coagulation, flocculation and sedimentation.
Cost of construction	Moderate to high	Relatively low
Cost of operation	Relatively low	Relatively high
Depreciation	Relatively low	Relatively high

c) Pressure filter:

Similar to rapid sand filters but the operation is housed within a cylindrical tank and the water passes through the filter while under pressure generated by a pump rather than by gravity [18] as shown in figure (2.6).

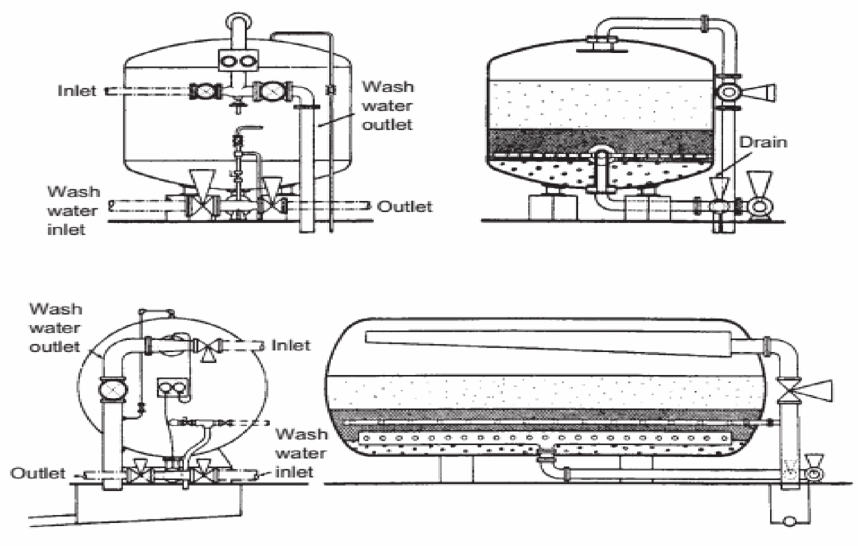

Fig (2.6): Pressure filter [51]

d) Diatomaceous earth filter:

It consists of a layer of diatomaceous earth above a septum or filter element and most suitable for low turbidity and low bacterial count source water. Coagulants and filter aids are required for effective virus removal [52].

e) Multimedia filter:

It consists of layers of various sizes of gravel, high-density garnet, sand, and anthracite coal.

f) Membrane filters:

Include ultra-filters and micro filters. These membranes use pressure as the driving force and are designed to remove particulates smaller than 10 micrometers [18].

2.2.1.13 Disinfection:

A process that inactivates pathogenic organisms in water by chemical oxidants or equivalent agents [55] both surface and ground water sources (subject to fecal contamination) typically requires disinfection to eliminate or inactivate microbiological populations [18].Disinfection is an effective barrier to many pathogens (especially bacteria) [27].There are two kinds of disinfection primary disinfection, and secondary disinfection. Primary disinfection achieves the desired level of microorganism kill or inactivation, Primary disinfection occurs early in the source water treatment, prior to sedimentation or filtration. Secondary disinfection maintains a disinfectant residual in the finished drinking water to prevent regrowth of microorganisms as water passes through the distribution system [35, 18].

a) Chlorination:

Chlorination (the addition of chlorine) is the most common method of disinfecting drinking water [35].Chlorine is the commonest disinfectant agent used for the disinfection of filtered water because it is cheap, efficient, reliable and harmless in acceptable level [56] that kills or inactivation of microorganisms still present in water and also effective against the bacteria commonly associated with waterborne diseases [57] and control of algae and other plant life since it is a powerful germicide and algaecide. Chlorine removes tastes and odor oxidizes iron and manganese, improves coagulation, and removes color [46, 27]. Usually chlorine gas is fed into the supply after the water has been clarified and/or softened [58].Chlorination is by far the most effective disinfectant for bacteria and viruses because of the residual disinfection effect that can last throughout the water [51].

b) Ozonation:

Ozone is a powerful oxidant and has many uses in water treatment, including oxidation of organic chemicals. Ozone can be used as a primary disinfectant. Ozone gas (O3) is formed by passing dry air or oxygen through a high-voltage electric field.

The resultant ozone enriched air is dosed directly into the water by means of porous diffusers at the base of baffled contactor tanks [27].Ozone disinfects microbes effectively and can easily penetrate the sturdy cell membranes of protozoa like Cryptosporidium [59].the main concern with using ozone as a disinfectant is that its "half-life" in water is only 30 minutes. If ozone alone is used as the disinfectant in large distribution systems (characterized by a residence time of 2 to 3 days), this residual concentration "half-life" is insufficient to maintain the microbiological integrity of the finished water. Use of ozone disinfection at large drinking water systems requires booster ozone additions or supplemental disinfection [18].

c) Ultraviolet Light Disinfection:

In ultraviolet (UV) disinfection, electromagnetic energy (UV radiation) is transferred from a mercury arc lamp to an organism's genetic material. The UV radiation penetrates microorganism cell membranes and destroys the microorganisms' ability to reproduce. The application of UV disinfection for source water treatment is limited because turbidity and suspended solids can render UV disinfection ineffective [60]. As with ozone disinfection, UV disinfection requires large drinking water systems to add a secondary disinfectant to maintain the microbiological integrity of the finished water [18] .Simultaneous treatment of water with UV and ozone results in higher microorganism kill than independent treatment with both UV and ozone [61]. Some other methods of disinfection are disinfection by iodine and bromine, disinfection with potassium permanganate, and disinfection with silver, called Operation Electra Katadyn [26].

2.2.1.14 Treated water storage:

A water supply system should include some form of treated water storage (reservoir)[60]Water storage requirements should take in to consideration the peak daily water use, the maximum day demand , the capacity of the normal and standby pumping equipment. Additional considerations include land use, topography, pressure needs, distribution system capacity, special demands, and the increased cost of electric power and pumps to meet peak demands. Water storage tanks are constructed of concrete, steel, or wood. Tanks may be constructed above or partly below ground, overflows must be well above the normal ground level and the bottom of the tank must be above groundwater or floodwater. Tanks located partly below ground must be at a higher level than any sewers or sewage disposal systems [61,62].The tank must be fitted with a robust lockable, and well fitting (but not airtight) lid to exclude light which tends to warm the water and encourage the growth of algae and pollutants. It is especially important to prevent the ingress of insects and animals and all openings must be protected using a fine mesh screen. The storage tank must be inspected regularly; at least annually and preferably every six months. If necessary, any accumulated silt can be flushed or siphoned out and the system disinfected [3].

2.2.1.15 Distribution systems:

The system of pipes, channels and vessels that store and convey from the treatment plant effluent line to the ultimate consumer .distribution system may include storage tanks, equalizing tanks, additional chlorination station with or without corrosion control facilities .the excellent water quality leaving the treatment plant is potentially threatened by the water quality problems characteristic of the distribution system: corrosion and sediment ,regrowth of bacteria in dead ends of the distribution system [61]. Unfortunately, the identification of risk on any distribution system can be difficult owing to the pipes and tanks etc. often being underground or hidden, which prevent or hamper inspection. Therefore the water quality impact of deficiencies in a system may not become evident until it manifests, either through monitoring (sampling and analysis), or more usually through objectionable taste, odor or appearance at the point of consumption [3].After treatment process, water should be checked before distribution to ensure its safety and compare with standard specifications. Water is tested in the laboratory by the tests below.

2.3 Water quality control:

Physical tests include Electric conductivity ,Color, Turbidity and Temperature [63].Chemical tests include pH, Total Solids, Total Suspended Solids, Hardness, Total Alkalinity, Chloride and free chlorine, fluoride, sulfate, Ammonia, Iron, Nitrite, nitrate, Manganese, sodium, potassium, Total hardness, calcium, Magnesium [64].Bacteriological test include Use of Bacteria as Indicators of Pathogenic Organisms in Water include Total Coliform, Fecal Coliform, Escherichia Coli, Fecal Streptococci, Enterococci and Clostridium perfringens. Methods for Detection and Enumeration of Bacteria in Water include Plating/Culturing Method, Viable Plate Count Procedure, Most Probable Number Method (Multiple Tube Technique) and Presence Absence Test [65].Biological testing (Microscopic) like blue green algae testing [66].

2.4 Drinking water standards:

The aim national of drinking water standards should be to ensure that the consumer enjoys safe potable water, Effective control of drinking-water quality is supported ideally by adequate standards and codes and their enforcement. As shown in table (2.2).

Table (2.2): A part of the Sudanese Standards [Sudanese Standards & Metrology Organization]

parameters	***Levels likely to give rise to consumer complains***
Physical parameters	
Color	15 TCU
Taste & odor	Acceptable
Temperature	Acceptable
Turbidity	5 NTU
PH	6.5-8.5
Inorganic Constituents	
Aluminum	0.2 mg/l

Ammonia	1.5 mg/l
Chloride	250 mg/l
Hydrogen sulfide	0.05 mg/l
Iron (total)	0.3 mg/l
Sodium	200 mg/l
Sulfate	250 mg/l
Total dissolved solids(TDS)	1000 mg/l
Zinc	3 mg/l
Nitrate as NO_3	33 mg/l
Nitrite as NO_2	2 mg/l
Manganese	0.27 mg/l
Fluoride	1.5 mg/l
Residual chlorine	0.2 mg/l

CHAPTER THREE

CHAPTER THREE

MATERIAL & METHODS

3.1 Introduction:

This chapter explains the methodology used to achieve the objectives of this study. Several methods were used to collect data through field visits, observation, reports and interviews where the study includes shedding light on some water treatment plants in Khartoum state, comparing treated water with Sudanese standards and determining their compliance with these standards.

The results of the daily analysis results were collected for eight consecutive months for four plants in the state, two plants located on the White Nile (Alshajra and Jabal Awlia) and two plants located on the Blue Nile (Bahri and Al-Muqrin). Samples were taken from the raw water (Intake) and treated water (reservoir).

Water samples were also taken from Al-Shajara and Al-Muqrin plants, and a complete analysis was conducted of them in the central laboratory.

3.2 study area:

Sudan, Khartoum state, Moqran, Alshajra, Jabal Awlia and Bahri .

3.2.1 Bahri Water Treatment Plant

Bahri water treatment plant is located in Bahri city in Khartoum state near Almak Nemer Bridge. Its geographical coordinates are 15.617147, 32.534778. As shown in Figures (3.1)

Fig (3.1): Aerial view for Bahri Water Treatment Plant.

3.2.2 Mogran Water Treatment Plant

Mogran Water Treatment Plant is located in Khartoum city. Its geographical coordinates are 15.605019, 32.502899. As shown in Figures (3.2)

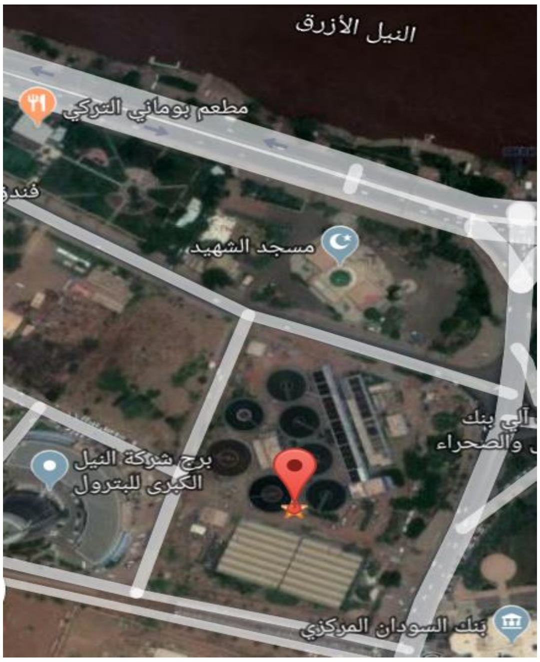

Fig (3.2): Aerial view for Mogran Water Treatment Plant.

3.2.3 Alshajra Water Treatment Plant

Alshajra Water Treatment Plant is located in Alshajra city. Its geographical coordinates are 15.533392, 32.483761. As shown in Figures (3.3)

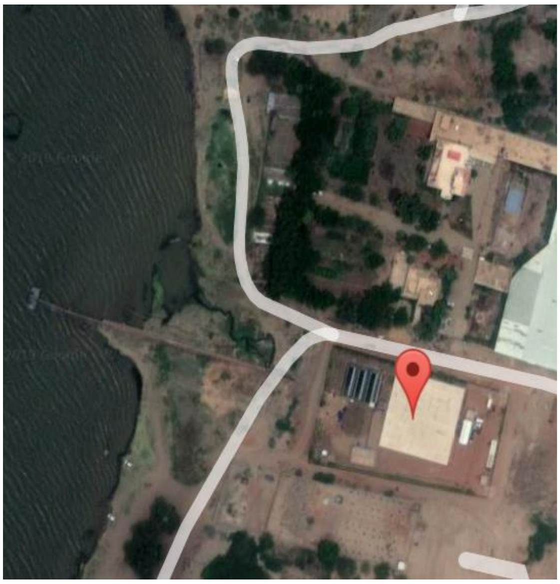

Fig (3.3): Aerial view for Alshajra Water Treatment Plant.

3.2.4 Jabal Awlia Water Treatment Plant

Jabal Awlia Water Treatment Plant is located in Jabal Awlia city. Its geographical coordinates are 15.234740, 32.493208. As shown in Figures (3.4)

Fig (3.4): Aerial view for Jabal Awlia Water Treatment Plant.

3.3 Tests conducted daily at plants:

3.3.1 Jar Test:

The purpose of an experiment knows the appropriate dose poly aluminum chloride to remove turbidity of water. I used a Jar test apparatus illustrates in (Figure 3.5) beakers, turbidity meter, measuring cylinders and sampling bottle. where has been added 0.5 ml of Poly Aluminum Chloride to the beaker and completed the mark with distilled water, I filled the bottles with raw water and put in the machine at a speed of 120 laps / Minute (quick mixing) for 2 minutes and diluted PAC doses were added in different quantities. After completing the fast mixing process, the speed set to 35 laps / Min (slow mixing) for 10 minutes. The waiting time was 30 minutes until the sedimentation was then measured turbidity. To know the appropriate dose for the plant, the equation is used (Laboratory dose) × Amount of water enters the plant per hour % 60.

Fig (3.5): Jar test device.

3.3.2Turbidity:

The test purpose is to determine the degree of turbidity of the water sample. I used 2100N Turbidity meter as shown in figure (3.6).The degree of turbidity was measured by a device 2100N Turbidity meter Based on light, the cell of the device was filled with 100 ml of the sample and placed in the device and given the reading and measured by unit NTU (Nephometric turbidity unit).

Fig (3.6): Turbidity meter.

3.3.3pH:

The purpose of the experiment is to determine the pH of water. I used pH Comparator as shown in figure (3.7), beaker and phenol red. Was measured pH by Color Comparator Method by used pH meter, The first two samples were taken plank and the other sample in addition to two points of the red phenol index, the device was moved until the color degree was matched between the sample and plank Recorded reading.

Fig (3.7): pH comparator.

3.3.4 Total Alkalinity:

The test was conducted to measurement total alkalinity in water .I used burette 25 ml, Porcelain dish, Magnetic stirrer and rod, Beaker 150 ml, Pipette Measuring cylinder 100 ml, pH meter, 0.02N Sulfuric acid, Methyl Orange indicator and Phenolphthalein indicator .Tested was conducted by (Indicator Method) .50 ml were taken from the sample and 3 drops of methyl orange were added and calibrated against dilute sulfuric acid until the color changed from yellow to orange.

3.3.5 Residual chlorine:

The experiment is done to determine residual chlorine in treated water. I used Chlorine Comparator, beaker and N.N-diethyl-p-phenylenediamine (DPD). Tested was conducted by (DPD Method).Glass cells were cleaned, rinse the glass cells with a sample, filled the left sample tube. 5 ml of the sample was placed in the left cell / tube, 5 ml of the sample was placed in the right cell / tube. The reagent (DPD) was added to a tube to the right of the cell. Rotates comparison wheel with a light source the color wheel rotates until the color in the test window matches the color in the blank window**.**

CAPTER FOUR

CAPTER FOUR

Results and Discussion

4.1 Alshajra water treatment plant

Alshajra water treatment plant is located on the bank of the White Nile in Alshajra area, which was established in 2016.The design capacity is 15000 cubic meters per day, and it is one of the modern plants in terms of the method of treatment where all processes of treatment are done in one stage contain three units for processing. Capacity of each unit is 500 cubic meters per day. The plant assists in feeding a number of its neighboring areas such as (Alshjra, Al-lamab, Almudraat, Yathrib, Alshaheed Taha Mahi, Jabra, Sharqah, Amariya, Nozha, Alazzozab, and Sebaq Alkheel). The plant was established to support the network of Alshjra area to fill the need due to increments of consumers.

4.1.1 Intake:

It consists of two main pumps, each of 800 cubic meters per hour, alternating every 15 days. The raw water is drawn by 10 mm pipes with a depth of 70 cm inside the Nile. The intake is shown in Fig (4.1).

Fig (4.1): Intake at Alshajra Water Treatment Plant

4.1.2 Flash Mixing:

The water comes from the intake pump and the poly aluminum Chloride is injected before entering the processing unit, where the rapid mixing process takes place 20 meters from the unit inlet.

4.1.3 Slow mixing:

The raw water passes through the pipes with a horizontal line of 400 meters and pressure of 15 bar and inter the treatment units, which are three compact units with a length of 23 meters and width of 6 meters and a height of 9 meters The interior is divided into three parts the length of each part 7.7 and the width of 2 meters and a height of 3 meters for each part. The slow mixing process is carried out inside the unit, so that the water is mixed with a PAC to the length of the unit with pipe outlets (2 inches with small holes) to enter the water slowly to reduce the pressure associated with the pump (15 Bar) and the process of mixing slow in a period not exceeding 30 minutes .Where the slow mixing process takes place in the first part of the unit.

4.1.4 Sedimentation:

It is in the second part of the unit where the Lamella cell is located. Lamella Is a sharp angle plates that increases the area used for sedimentation. Due to the force exerted on the suspended particles, the weight is down and the flow is in the direction of the slope of the plates and has the ability to deposit the particles on the surface of the lamella. When deposited on the surface, the forces that affect it become the weight down (gravity). The particles slide to the bottom of the pelvis. This improves the deposition efficiency at this stage.

4.1.5 Filtration:

Water enters through 9 holes to the 3 layer filters with 2-4 gravel (200 mm), 1-2 medium sand (100 mm) and 5-1 fine sand (400 mm). Water Spread through them to remove impurities. The media of the filter is cleaned by the back washing process to get rid of the sediments and suspenders. The sand is cleaned by water and air. Filters are washed and the washing process usually lasts for 10-15 minutes. As shown in Figure (4.2).

Fig (4.2): Treatment units at Alshajra Water Treatment Plant

4.1.6 Disinfection:

After the filtration process, the water passes through the conveyor line where chlorine is injected .so that the Water enters the store a sterile.

4.1.7 Storage:

After disinfection of water flows into tank with capacity of 3200 cubic meters tank, a length of 40 meters and a width of 20 meters and a height of 2 meters. The tank is divided into two parts each part of 40 meters length and 20 meters width, pour water on both parts north and south of the productivity of 550 cubic meters per hour for three units. As shown in Figure (4.3).

Fig (4.3): Water storage tank at Alshajra Water Treatment Plant

4.1.8 Distribution System:

Water is withdrawn from the store by three pumps .The first pump pulls 250 cubic meters per hour the pumps (2, 1) pulls 600 cubic meters per hour .

4.2 Jabal Awlia Water treatment plant:

Is located on the banks of the White Nile, was established in 2010 in the area of Jabal Awlia near the Jabal Awlia dam with design capacity 68000 Cubic meters per day. The plant feed many areas including Jabal Awlia and its environs, Alkalakla, Alfitah, Tiba, Salmaniya, Dar Al salaam and part of Azhari ...etc.).

4.2.1Intakes:

Consists of a basin for collecting water (turbid water well) located at the end of the intake pipes are collected water until the lifting of the treatment units. Water passes through gates with medium size screens before entering the well. The intakes consist of 4 Submersible pumps pull each one of them 1100 Cubic meters operate two of them and two reserves). The water accumulates in the conveyor line diameter of each pump by a conveyor line diameter (800 inch). After water enters the plant, the amount of water is measured by flow meter. As shown in Figure (4.4).

Fig (4.4): Intake at Jabal Awlia Water Treatment Plant

4.2.2 Flash mixer:

Poly aluminum chloride is added before water enters the flash mixing tank. Sometimes initial chlorine is added. The duration of rapid mixing does not exceed 1min. As shown in Figure (4.5).

Fig (4.5): Pac dosing champers and flash mixing at Jabal Awlia Water Treatment Plant.

4.2.3 Sedimentation (pulsator):

After rapid mixing, water flows into the sedimentation basins and their number 3 Basins along 20m Show19m Height 3m. As shown in Figure (4.6).

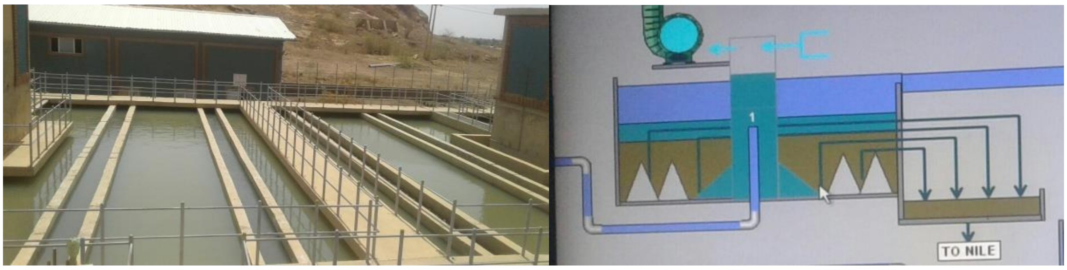

Fig (4.6): Sedimentation basin (Pulsator) at Jabal Awlia Water Treatment Plant.

4.2.4 Filtration:

The water accumulates after the sedimentation process in a large basin and goes to rapid sand filters and their number 8 Filters length 13m, width 6.5, Height 3m, consists of sand 1m (1.25 -0.8mm). And nozzles to collect filtered water (8m Length, 8m width, and 14m Height). The water enters the filter from the top and passes through the sand layer and then the nozzles. The plant has recovery water basin to collecting water with length 4.3m, width 8.50, High 4.70. As shown in Figure (4.7).

Fig (4.7): Rapid sand filters at Jabal Awlia Water Treatment Plant.

4.2.5 Low Pressure Pumps:

4 Pumps pulls 1000 Cubic meters per hour. As shown in Figure (4.8).

Fig (4.8): low pressure pumps at Jabal Awlia Water Treatment Plant.

4.2.6 Disinfection:

Chlorine is added for disinfection in the ground tank of each1000 Cubic meters of water, 1 Kilos of chlorine. As shown in Figure (4.9).

Fig (4.9): Disinfection system at Jabal Awlia Water Treatment Plant.

4.2.7 Storage:

The station has an overhead tank (above the mountain) with its capacity1200 Cubic meters divided into two parts with a capacity of each part 6000 Cubic meters. As shown in Figure (4.10).

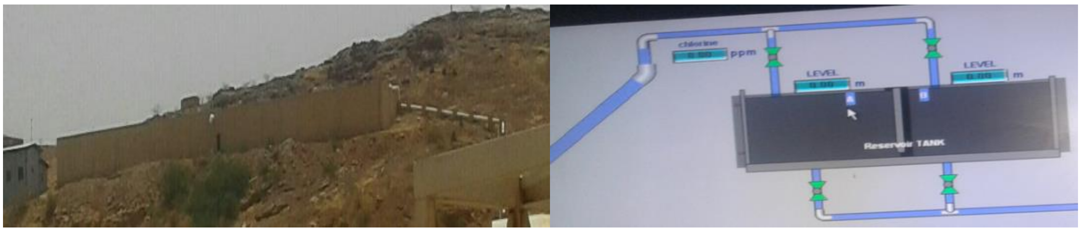

Fig (4.10): Reservoir at Jabal Awlia Water Treatment Plant.

4.2.8 Distribution:

4 Pumps pulls 500 Cubic meters per hour and 3 Pumps pulls 400 Cubic meters per hour.

4.3 Al-Mogran Water treatment plant:

Al-Moqran Water plant is located on the Blue Nile, which was established in 1964 with a design capacity of 72,000 cubic meters per day. The plant was expanded in 1993 to a design capacity of 90,000 cubic meters per day; new units were added to the plant in 2018 producing 45,000 Cubic meters per day to a design capacity of 135,000 cubic meters per day. The output of the current plant is 84,000 cubic meters per day as the new units are stopped. The Mogran water plant feeds several neighboring areas such as [Khartoum, Al Mogran, Presidential Palace, Rumaila, Al Diym, Hillah, parts of the city of Omdurman (Abu Saad, Part of pant, Part of the Umpda, part of the Abasia, Almohndsen, Doha)]

4.3.1Intake:

It is consisting of 4 pumps distributed over two lines the productivity of the first line 1700 meters Cubic per hour and the second 1600 cubic meters per hour, any line has three pipes with diameters (55, 55, and 61). As shown in Figure (4.11).

Fig (4.11): Intake at Mogran Water Plant

4.3.2Flash mixing:

After the addition of poly aluminum chloride, the water enters flash mixing basin which are 120 m long, 120 m wide and 2 m high. There are five mixers in the basin to mix the materials (poly aluminum chloride). Water is kept in a quick mixing basin (30-50 sec) Rotation speed 120 rpm. Determine dose PAC According to the dose of the laboratory where the dose is tested PAC which gives the most appropriate degree of turbidity compared to the Sudanese and global specifications. As shown in Figure (4.12).

Fig (4.12): Flash mixing at Mogran Water Plant.

4.3.1 .3Flocculation and Flotation:

It consists of five basins with a circular shape diameter 10 meters depth of 7 meters and two basins in the same dimensions in the new plant. The time of water retention 30 minutes in the basin with rotation speed is 50 rpm. In each basin a slow blender mixer works to prevent siltation. The silt is disposed of in a discharge hole located below.

4.3.4 Sedimentation:

It consists of five basins of circular shape 28 m in diameter, 8 m depth in addition to tow basins in the same dimensions in the new plant. The detention time of water in basin is one hour and half. The sediment is disposed by scraper to the drain. As shown in Figure (4.13).

Fig (4.13): Sedimentation basin at Mogran Water Plant.

4.3.5 Filtration:

After the sedimentation process, the water is transferred to the filtration process to dispose of the suspended material in 18 rapid sand filters in the old plant .and 9 filters in the new plant. The depth of the filter is 1.20 m and the length is 8 meters and the width is 5 meters. Sand filter consists of sand with diameter ranges (0.4-0.2mm) in depth 0.35-0.40 m and grit diameter (0.8-1.5 mm) in depth 0.15 -.20 m. The water passes through the sand, then the gravel, then into the fountains, and into the tank of filtered water. As shown in Figure (4.14).

Fig (4.14): Rapid Sand Filter at Mogran Water Treatment Plant.

4.3.6 Disinfection (chlorination):

After the water is out of the filters and before reaching the main tank pass through the low pressure basin with a capacity of 4000 cubic meters where the chlorine right in the form of gas .Is added 1 kg of chlorine per thousand cubic meters of water, chlorine and water remains in contact period of half an hour before sending the sterile water into the main store.

4.3.7 Storage:

The plant has a ground tank, 90000 cubic meters, divided into two parts to facilitate cleanliness and maintenance. The tank has a buoy that gives a signal to the input pumps before filling and stops automatically until the water level of the tank drops to a specific range. Figure (4.15) shows reservoir and distribution network.

Fig (4.15): Reservoir and distribution network at Mogran Water Treatment Plant.

4.4 Bahri Water Treatment Plant:

Bahri water plant is located on the banks of the Blue Nile in the city of Bahri and is the largest plant in Sudan in terms of productivity and an estimated production of 300,000 cubic meters per day. It was created in three stages. Factory A was established in 1954, its intake consists of two pumps, each pumping 1600 cubic meters per hour, two sedimentation basins with a capacity of 1000 cubic meters, 8 rapid sand filtration ponds, 3 low pressure pumps, 4 high pressure pumps, With a main storage capacity of 5000 m3 and an overhead tank with a capacity of 500 m3 to collect water from the network, the plant A feeds a South Bahri area with a production capacity of 30,000 m3 / day. plant B was established in 1986, and its intake consists of 6 Various production pumps, two sedimentation basins with a capacity of 1000 cubic meters each, 10 quick sand filter tanks, filtered water storage collection of (B) and (C). Cut. The plant feeds a number of areas in Bahri and Omdurman. The C plant was established in 1999. Its intake has 5 pumps that pull each pump 125 cubic meters per hour, four sedimentation tanks with a capacity of 8000 cubic meters, 18 rapid sand filtration basins, and 8 low pressure pumps, 5 of which feed Al-Sahafah is a high-pressure station, each pump produces 600 cubic meters per hour, 3 of which feed the high-pressure Bahri plant, and each pump produces 950 cubic meters per hour.

4.4.1Intake:

As shown in Figure (4.16).

Fig (4.16): Intake at Bahri Water Treatment Plant.

4.4.2Flash mixing:

Water is drawn from the Nile through pipes to the rapid mixing basins, which are 120 m long, 120 m wide and 2 m high. Where chemicals are added, there are five mixers in the basin to mix the materials (poly- ammonium chloride). As shown in Figure (4.17).Water is kept in a quick mixing basin (30-50 sec) Rotation speed (150-100) rpm. Determine dose PAC According to the dose of the laboratory where the dose is tested PAC which gives the most appropriate degree of turbidity compared to the Sudanese and global specifications.

Fig (4.17): Flash mixing basin at Bahri Water Treatment Plant.

4.4.3 Flocculation and Flotation:

It consists of five rotations with a circular shape diameter 1 0 meters depth of 7 meters and tow basin in the same dimensions in the new plant.

The time of water retention 30 minutes in the basin with rotation speed is 50 rpm.

In each basin a slow blender mixer works to prevent siltation .There are also openings through which the water comes out after undergoing the detoxification process .The silt is disposed of in a discharge hole located below.

4.4.4 Sedimentation:

It consists of five basins of circular shape 28 m in diameter, 8 m depth in addition to tow basins in the same dimensions in the new plant as shown in Figure (4.18). The detention time of water in basin is one hour and half .The sediment is disposed by scraper to the discharge hole.

Fig (4.18): Flocculation and Sedimentation basins at Bahri Water Treatment Plant.

4.4.5 Filtration:

After the sedimentation process, the water is transferred to the filtration process to dispose of the suspended material in 18 rapid sand filters in the old plant. Plus 9 filter in the new plant as shown in Figure (4.19). The depth of the filter is 1.20 m and the length is 8 meters and the width is 5 meters. Sand filter consists in diameter ranges (0.4-0.2) mm in depth (0.35-0.40 m) and grit diameter (0.8-1.5) mm in depth (15.-20.) M. Filtration rate 50 m3 / h. The water passes through the sand, then the gravel, then into the fountains, and into the pool of filtered water. The valve is automatically cleaned. The filter valve is locked and the air valve is opened for 3 minutes. The air valve is closed. The valve is opened for 5 minutes. The water used in the reverse washing process is pumped from the treated water tank. The valve is closed. And after 2 minutes the Filtration valve is opened. A single filter is needed for 10 cubic meters of water, discharged into the outlet.

Fig (4.19): Rapid sand filters at Bahri Water Treatment Plant.

4.4.6 Disinfection (chlorination):

After the water is out of the filters and before reaching the main tank pass through the low-pressure basin with a capacity of 4000 cubic meters where the chlorine right in the form of gas.

Is added 1 kg of chlorine per thousand cubic meters of water, chlorine and water remains in contact period of half an hour before sending the sterile water into the main store.

4.4.7 Storage:

The plant has a ground tank, 90000cubic meter, divided into two parts to facilitate cleanliness and maintenance. The tank has a buoy that gives a signal to the input pumps before filling and stops automatically until the water level of the tank drops to a specific range.

4.5 The effect of treatment On Turbidity:

As described in earlier chapters, several laboratory investigations have been carried out in this research work. The investigations have been conducted for the collected samples (i.e. from four different treatment plants at Khartoum state site area). The effects of treatment on turbidity of raw water were investigated to construct table (4.1a) to (4.4b).

As expected, the turbidity of raw water on the Blue Nile plants (Bahri and Mogran) decreased in June and increased significantly in July, August, September and October, then decreased in November, December and January.

The laboratory investigations of White Nile treatment plants (Alshajra and Jabal Awlia) revealed the highest turbidity value in June, July, and August and gradually decreased until January.

From the above results it can be noticed that the increment of raw water turbidity value in June, July, August, September and October associated with flooding season and opening of the dam's gates.

For treated water, it is clear that the highest turbidity values in Bahri plant in June, July, August and September peaked in October (are considered very high as referred to the Sudanese standards) and decreased significantly in November, December and January to meet specifications.

As shown in tables (4.1a) and (4.1b) the lowest values of turbidity of treated water at the Mogran plant in June and July then increased in August and September and began to decrease from mid-October January. These results indicated that treated water often fail to satisfy specifications

For Alshajra plant tables (4.3a) to (4.3b), the fluctuation of treated turbidity values can be noticed. The highest values of turbidity in late June and early July began to decline until increases in late December and declined in late January. These results often out of range of standard.

Tables (4.4a and 4.4b) show the results of turbidity of the Jebel Awlia plant. It can be seen the turbidity values of treated water was oscillating from June to October and decreased in November, December and January. However, the low turbidity of the treated water at Jabal Awlia plant is not satisfying the specifications.

4.5.1 Mogran treatment plant:

Table 4.1a: Water quality results of Turbidity in raw and treated water at Mogran plant.

	June		July		August		September	
DAYS	Tur(IN)	Tur(OUT)	Tur.(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)
1	128	1.03	5456	2.02	6488	44.6	2980	9.2
6	285	1.75	14992	9.8	5874	4.21	2535	141
11	381	1.37	8570	11.4	4320	20	3090	24.2
16	420	51.9	14022	23.9	4905	15.8	1458	269
21	405	4.3	11218	13.2	4880	16.8	922	24.4
26	752	3.07	6520	2.65	5782	18.4	713	58.7
30	2320	4.9	7848	8.3	3732	9.8	752	21.2

Table 4.1b: Water quality results of Turbidity in raw and treated water at Mogran plant.

	October		November		December		January	
DAYS	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)
1	715	37	313	14.5	46.9	9.31	128	14.7
6	750	18.5	215	9.20	43.0	11.7	79	19
11	530	67.4	126	22.3	34.2	6.90	75	18.7
16	191	26.1	110	15.2	103	1.33	72.6	18.1
21	302	4.4	90	3.33	118	12.6	72.8	6.0
26	570	11	74.2	2.07	100	24	80.1	6.8
30	641	3.30	49.4	14.8	141	22.9	84.2	8.3

4.5.2Bahri treatment plant:

Table 4.2 a: Water quality results of Turbidity in raw and treated water at Bahri plant.

	June		July		August		September	
DAYS	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)
1	50.6	8.7	2973.3	16.5	9815	22.3	3486	14.2
6	182.3	5.8	8060	32.5	6273	34	4545	16
11	283	11.3	9856	15.1	4550	20.8	2665	23.2
16	360	8.5	1775.1	20.4	5575	12.8	1747	24.7
21	432	9.8	9520	13.3	6453	14.1	586	21.3
26	491	13.5	11410	19.2	4896	13.3	494	27.4
30	1584	28.4	8803	21.5	2760	14	450	8

Table 4.2b: Water quality results of Turbidity in raw and treated water at Bahri plant.

	October		November		December		January	
DAYS	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)
1	449	29.5	1448	10.3	43.8	5	9.9	5
6	351	33	231.8	5	36.2	2.2	9.5	4
11	309	28.2	96	4.4	15.3	4.7	9.5	2.8
16	229.2	13.8	98.5	2	16	4	7.9	2
21	195	15.5	101	3.9	9.8	3.8	6.0	1.3
26	416	76.8	75.1	5	9.4	3	9.4	4
30	408	65.5	60.8	4.9	11.4	5	9.1	5.6

4.5.3 Alshajra treatment plant:

Table 4.3a: Water quality results of Turbidity in raw and treated water at Alshajra plant.

	June		July		August		September	
DAYS	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)
1	118	25	167	161	106	68	95	18
6	100	18.9	174	20.6	113	12.6	82	16
11	410	18.2	542	31.6	112	15.6	73	7.0
16	198	25.4	152	8.3	117	22.1	69	7.0
21	161	52.7	117	6.8	126	40	73	12.0
26	214	30.5	157	40.6	110	24	78	13.0
30	161	157	111	9.0	97	11	81	10

Table 4.3b: Water quality results of Turbidity in raw and treated water at Alshajra plant.

	October		November		December		January	
DAYS	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)
1	118	17	60	15	56	7	50.1	20.4
6	62	10	59	15	64	8.0	46.4	17.2
11	83	12	65	11.0	52	9.0	49.5	8.0
16	62	9	60	9.0	57	10.0	39.4	19.5
21	63	9	61	11.0	50.8	14.7	35.8	29.3
26	70	9	66	11	49.7	10.5	34.2	5
30	52	8.0	60	9	46.7	34.3	37.3	5.9

4.5.4 Jabal Awlia treatment plant:

Table 4.4a: Water quality results of Turbidity in raw and treated water at Jabal Awlia plant.

	June		July		August		September	
DAYS	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)
1	288	4.0	647	20.6	120	8.5	72	5
6	129	7.0	241	14.3	107	12	53	7.7
11	736	14	221	16.6	90	6.5	49.5	9.5
16	314	13.4	242	16.3	55	11	51	7
21	560	16	271	12.3	74	6.6	53	16.4
26	290	30	162	10	81.2	7.6	48	12
30	408	8	150	7.3	98	7	45	21.7

Table 4.4b: Water quality results of Turbidity in raw and treated water at Jabal Awlia plant.

	October		November		December		January	
DAYS	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)	Tur(IN)	Tur(OUT)
1	58	21.3	25.5	5.8	25	7.1	21.1	7.8
6	34	8.4	22	6.0	24.8	5.8	24	8
11	34.2	10.2	23.6	7.3	22	6.5	32.6	9.7
16	22.4	8.4	26	7.0	30.5	5.3	34.4	9.5
21	22.2	6.8	30	7.5	21	6.0	32	9.6
26	21.4	5.5	24.5	5.5	24.9	6.7	22.5	6.0
30	29	7.7	25.8	6.4	22.5	6.0	29.6	5.6

4.6The effect of treatment on total alkalinity:

The effect of treatment on total alkalinity for treated water presented in figures (4.1) to (4.24).

Figures (4.1) to (4.24) show that the increase of PAC concentration decreases the total alkalinity values in different degrees.

Furthermore, Figures (4.20) to (4.51) show that there are daily changes in Total alkalinity of raw water in Blue Nile and White Nile. This situation is associated with flooding season.

According to the above-mentioned results it is demonstrated that the treated water for all investigated treatment plants satisfy the specification for total alkalinity.

4.6.1 Moqran treatment plant:

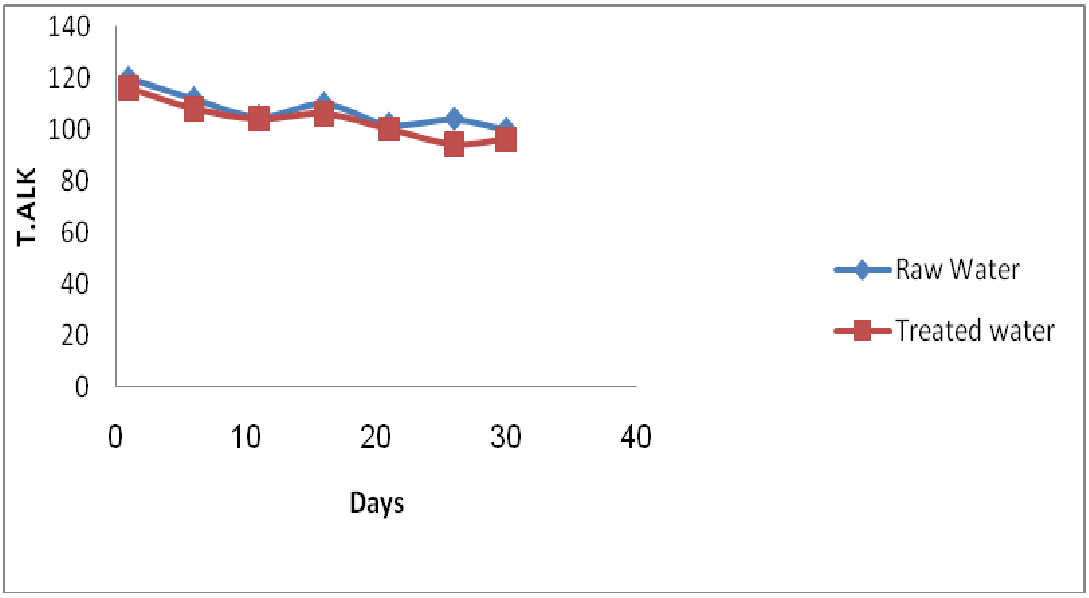

Fig (4.20): Total Alkalinity of the raw and treated water at Mogran plant in June.

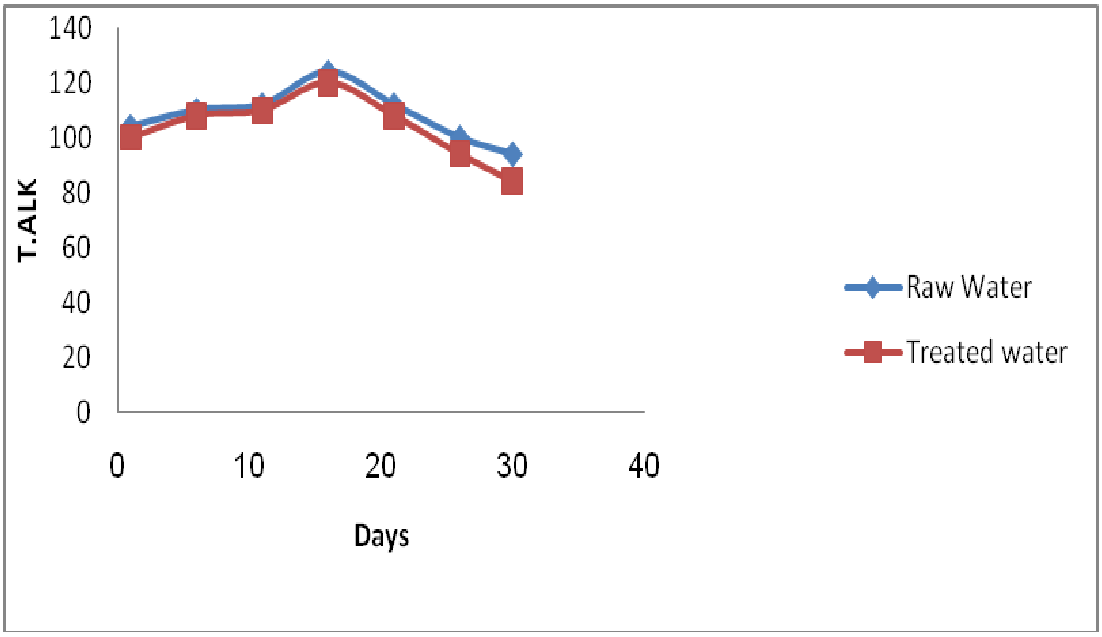

Fig (4.21): Total Alkalinity of the raw and treated water at Mogran plant in July.

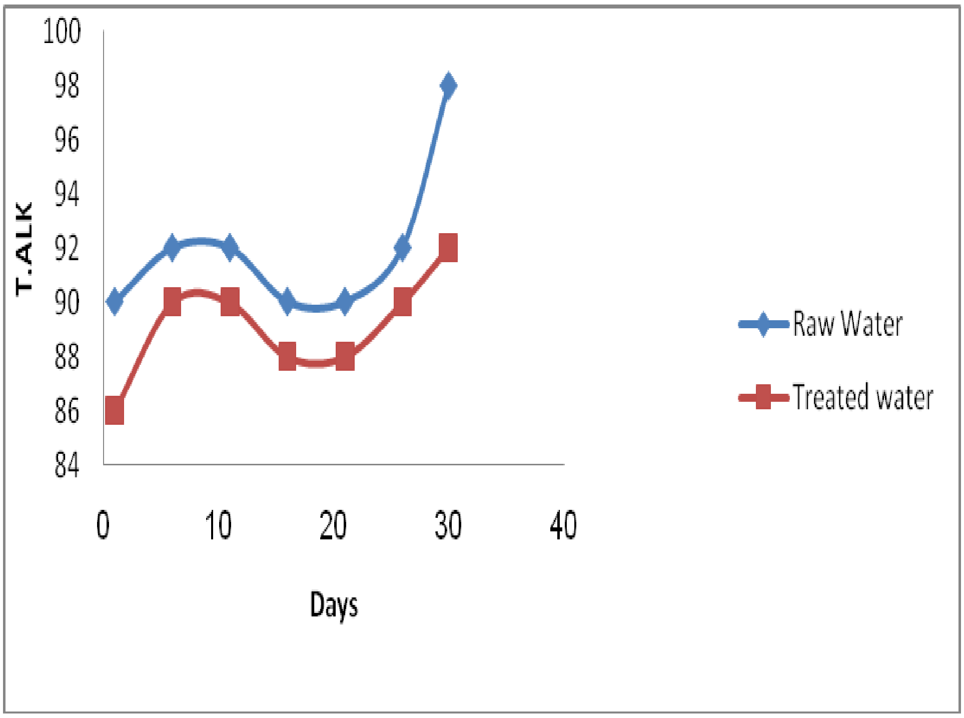

Fig (4.22): Total Alkalinity of the raw and treated water at Mogran plant in August.

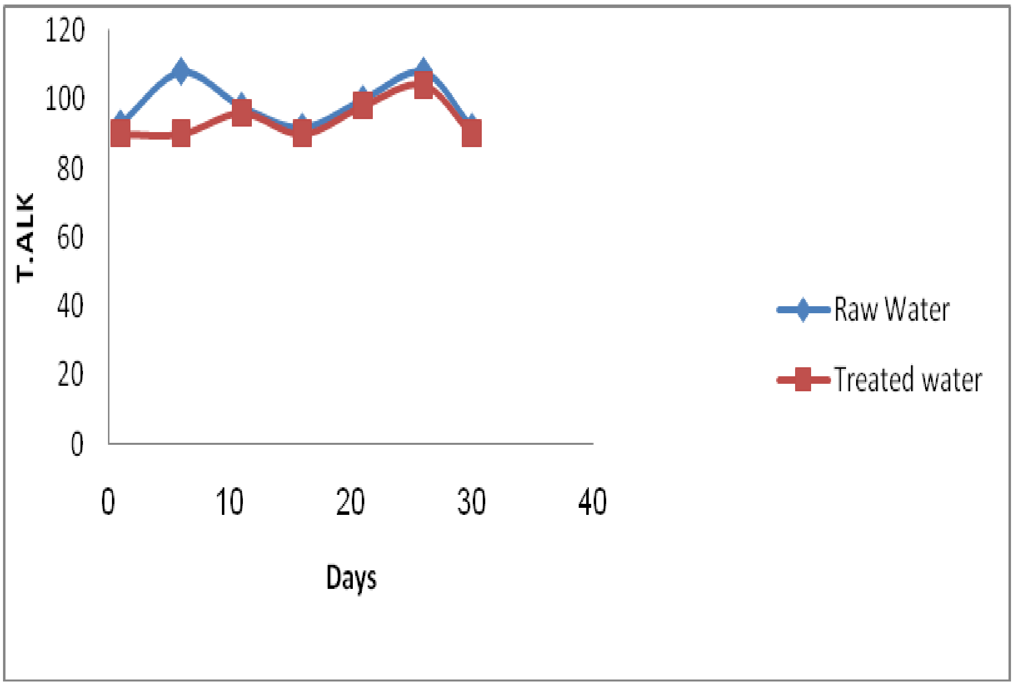

Fig (4.23): Total Alkalinity of the raw and treated water at Mogran plant in September.

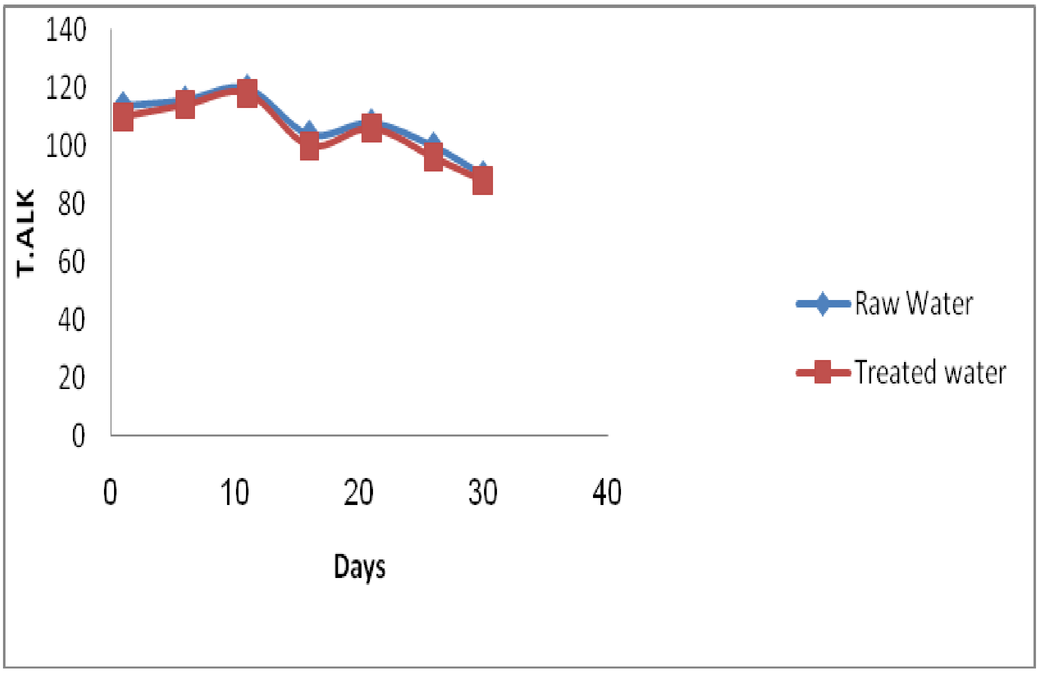

Fig (4.24): Total Alkalinity of the raw and treated water at Mogran plant in October.

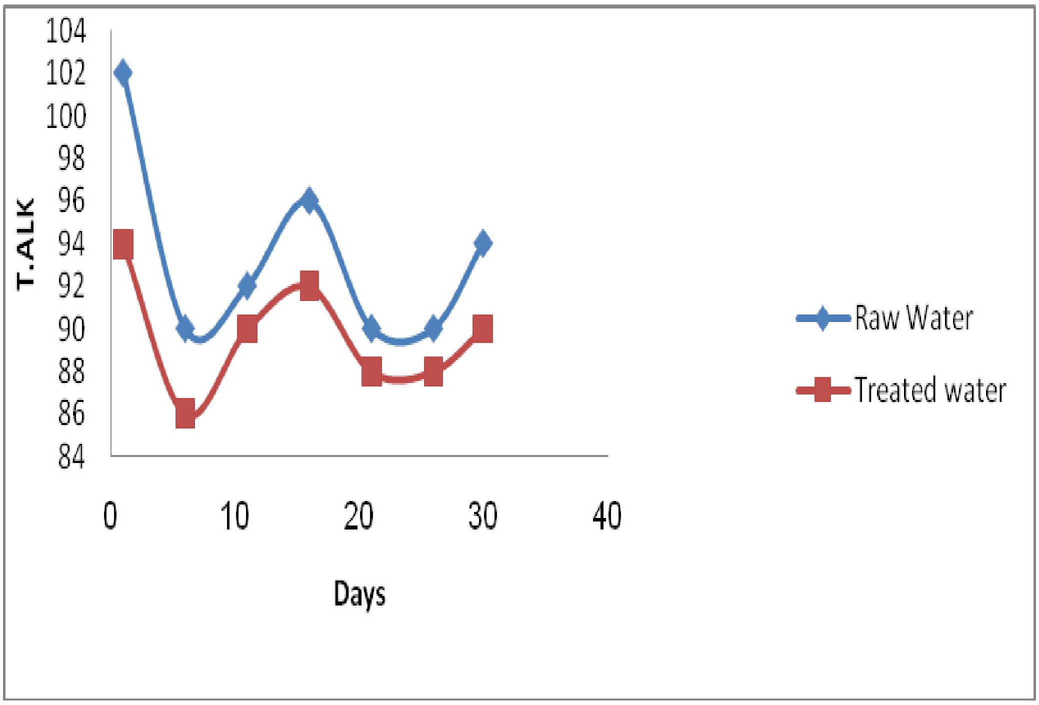

Fig (4.25): Total Alkalinity of the raw and treated water at Mogran plant in November.

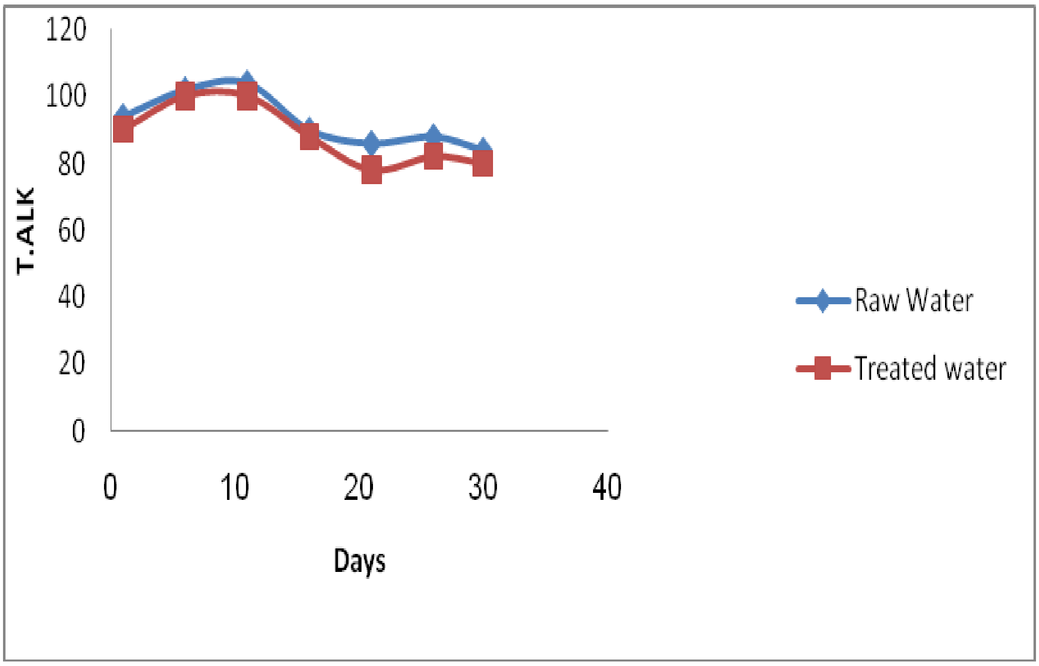

Fig (4.26): Total Alkalinity of the raw and treated water at Mogran plant in December.

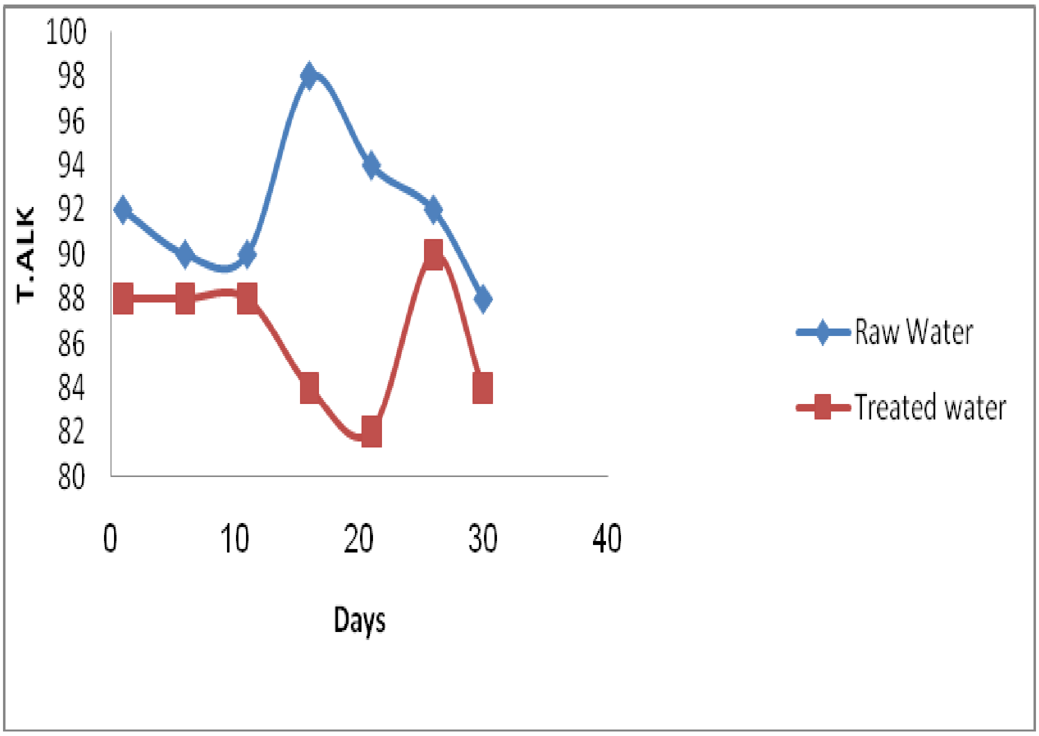

Fig (4.27): Total Alkalinity of the raw and treated water at Mogran plant in January.

4.6.2 Bahri treatment plant:

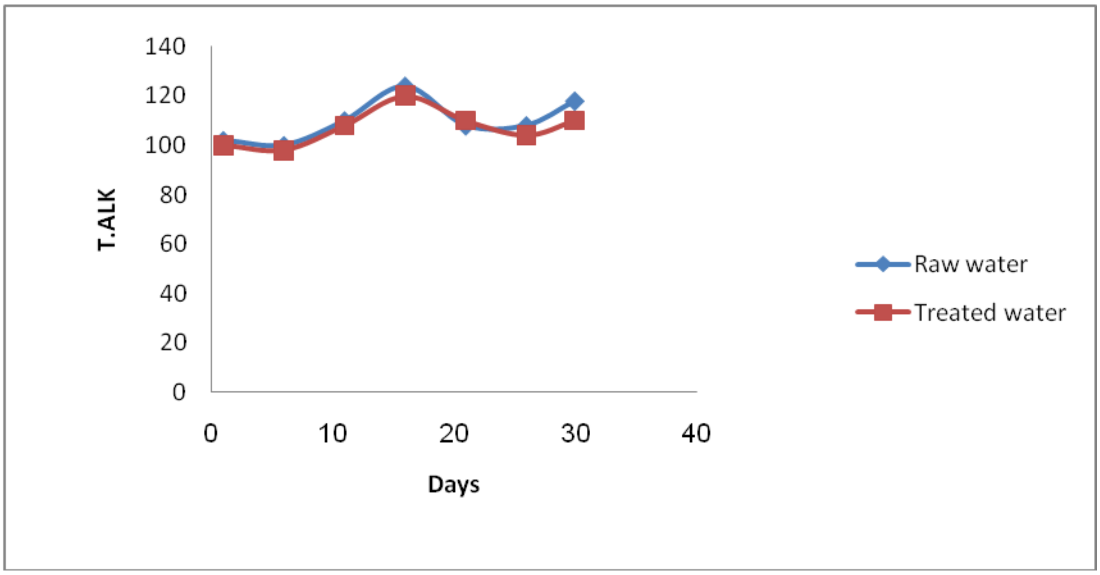

Fig (4.28): Total Alkalinity of the raw and treated water at Bahri plant in June.

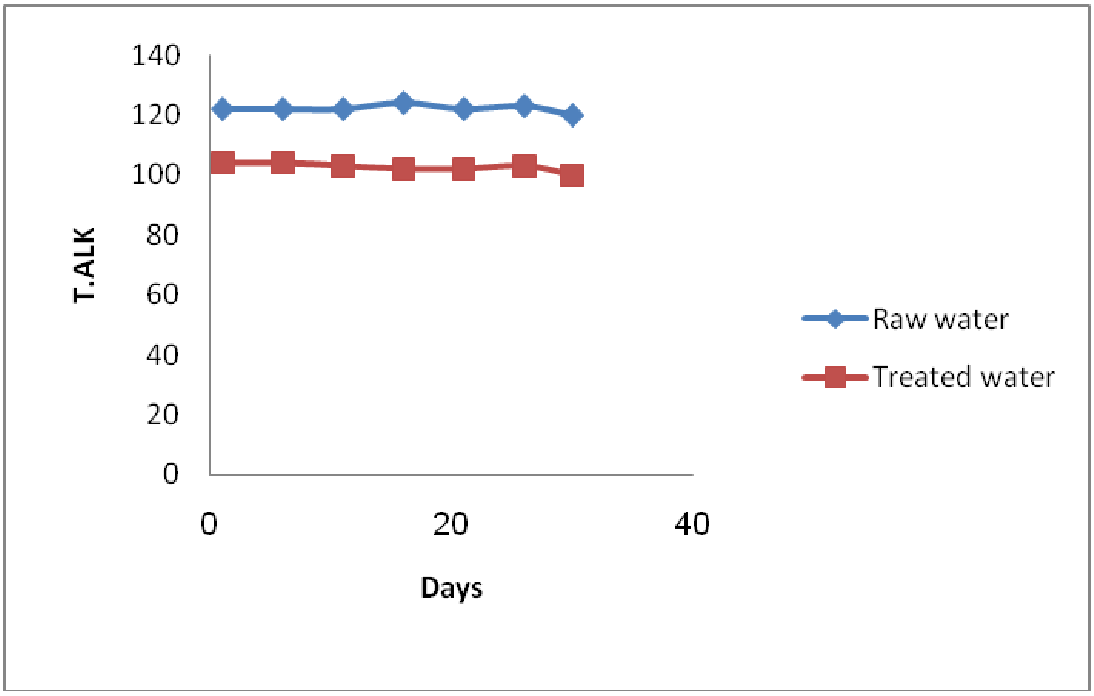

Fig (4.29): Total Alkalinity of the raw and treated water at Bahri plant in July.

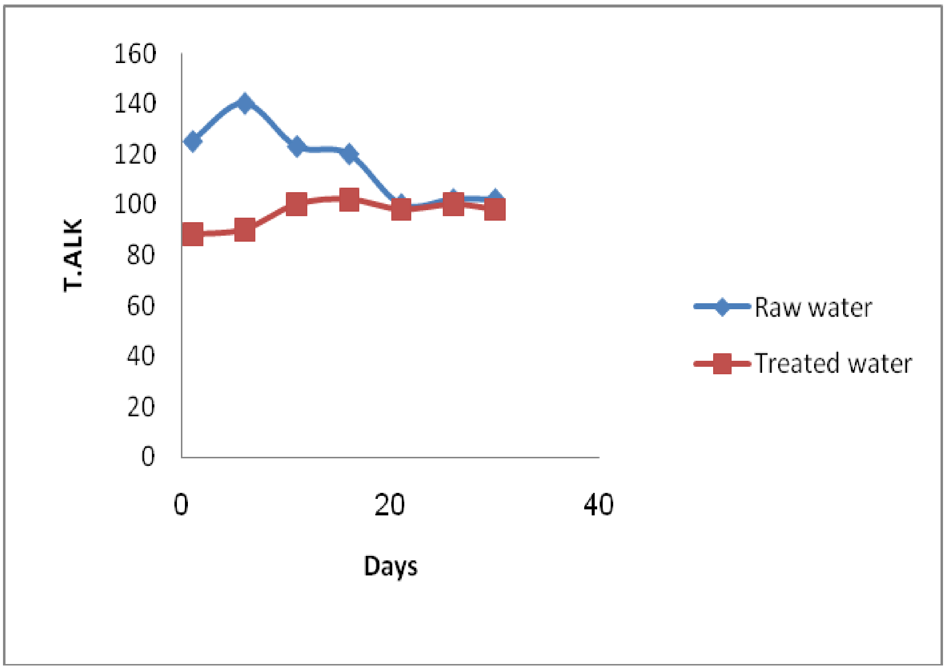

Fig (4.30): Total Alkalinity of the raw and treated water at Bahri plant in August.

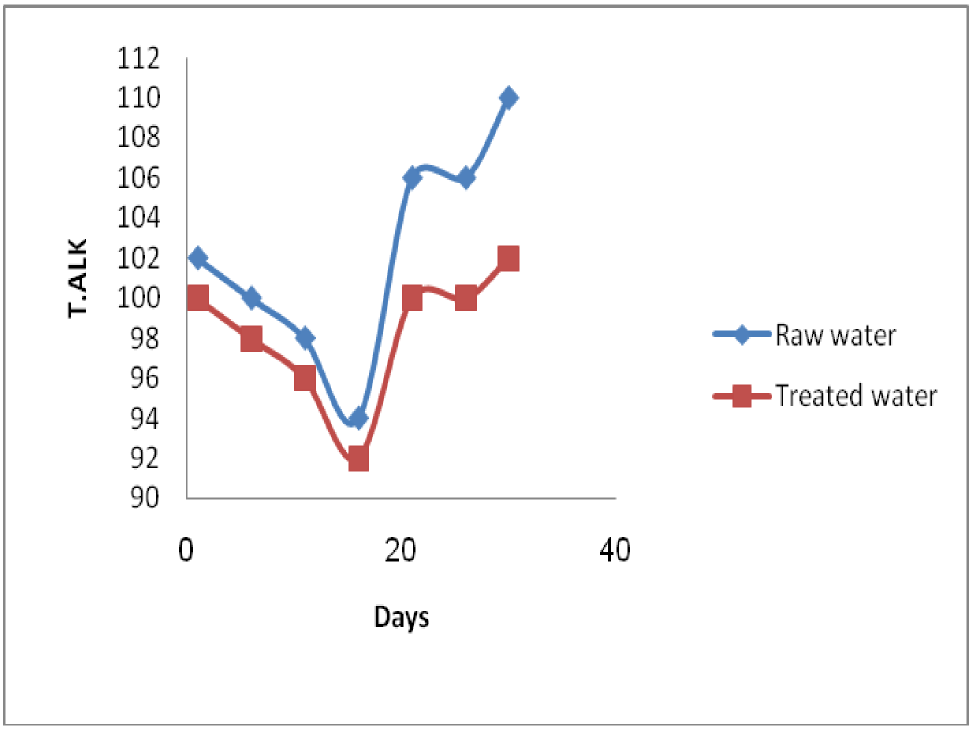

Fig (4.31): Total Alkalinity of the raw and treated water at Bahri plant in September.

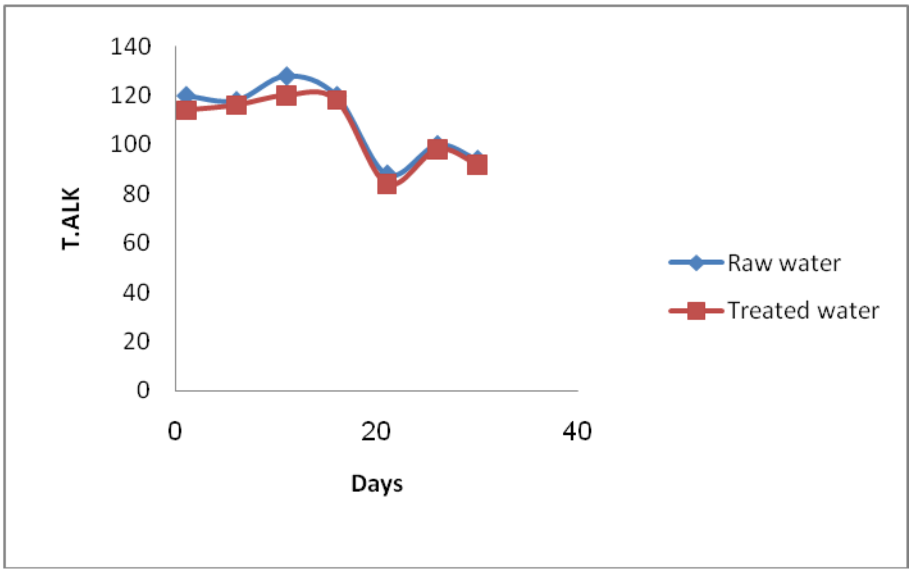

Fig (4.32): Total Alkalinity of the raw and treated water at Bahri plant in October.

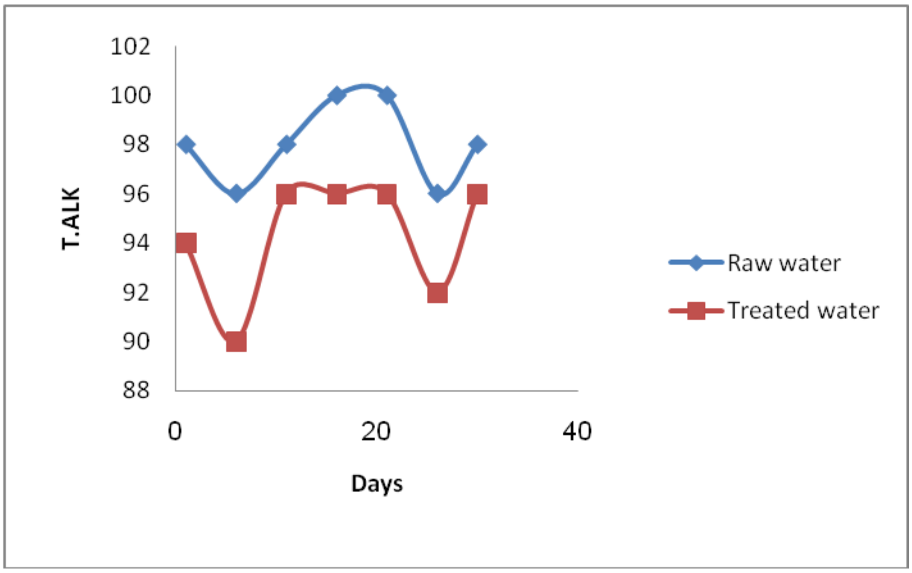

Fig (4.33): Total Alkalinity of the raw and treated water at Bahri plant in November.

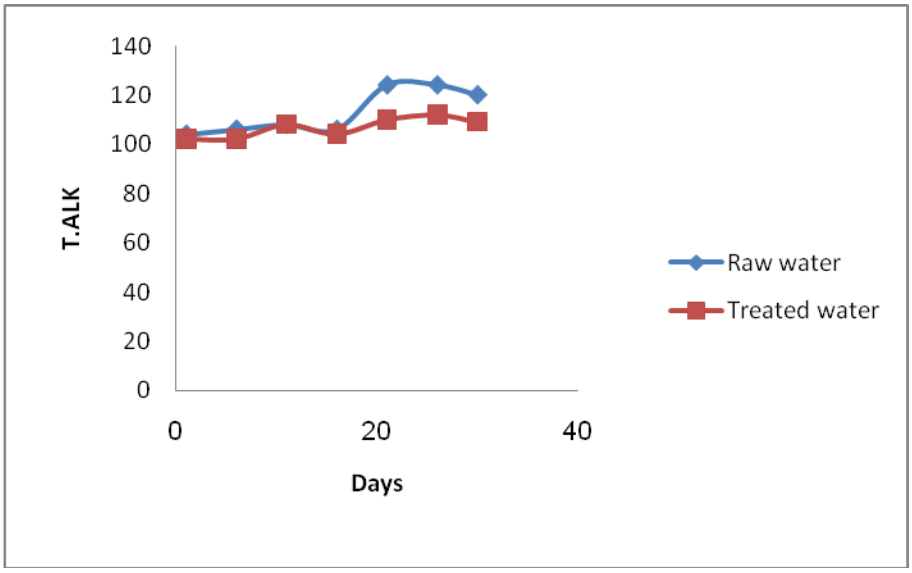

Fig (4.34): Total Alkalinity of the raw and treated water at Bahri plant in December.

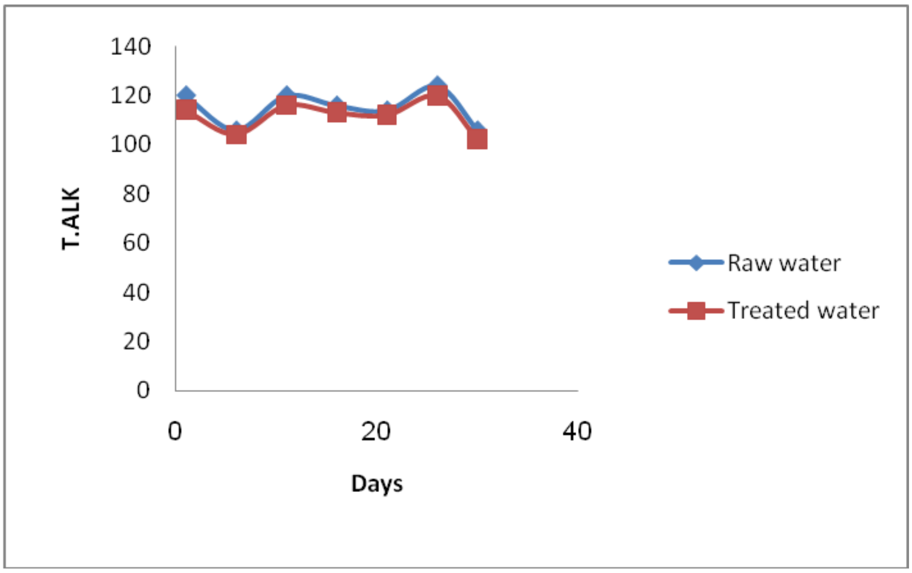

Fig (4.35): Total Alkalinity of the raw and treated water at Bahri plant in January.

4.6.3 Alshajra treatment plant:

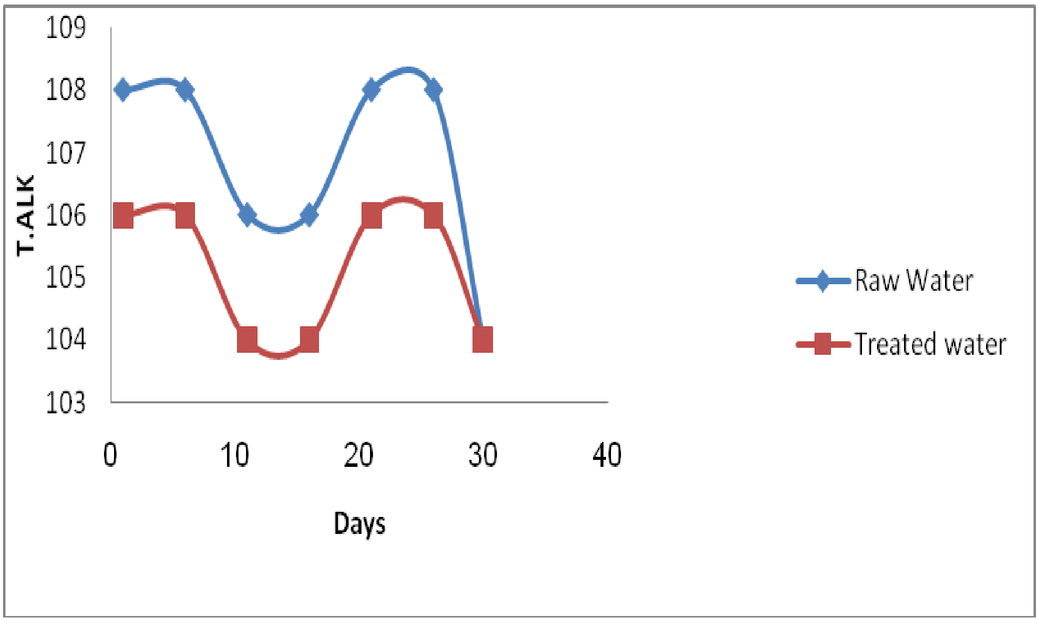

Fig (4.36): Total Alkalinity of the raw and treated water at Alshajra plant in June.

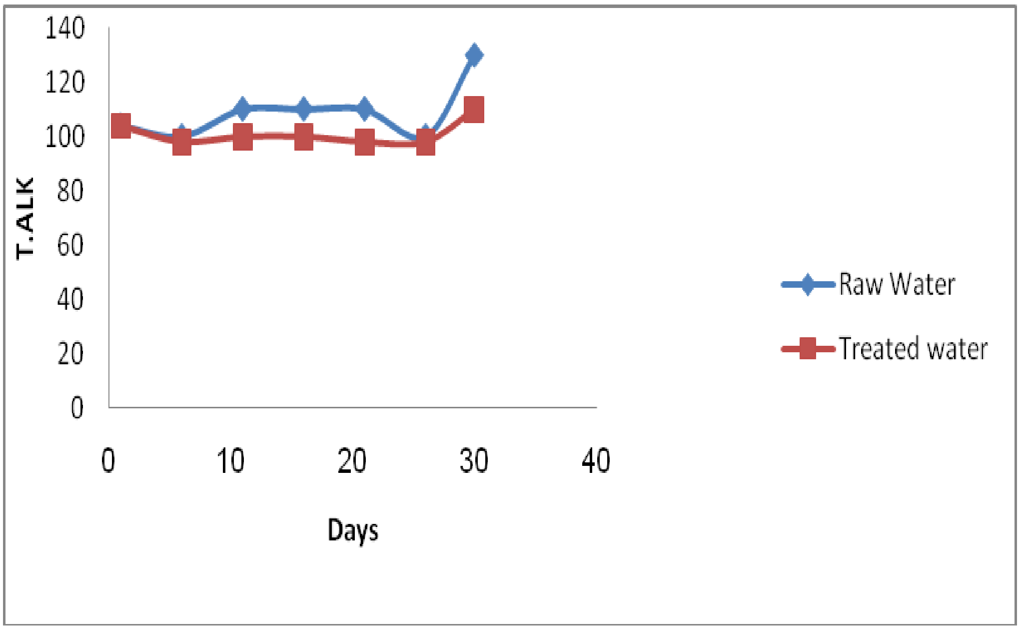

Fig (4.37): Total Alkalinity of the raw and treated water at Alshajra plant in July.

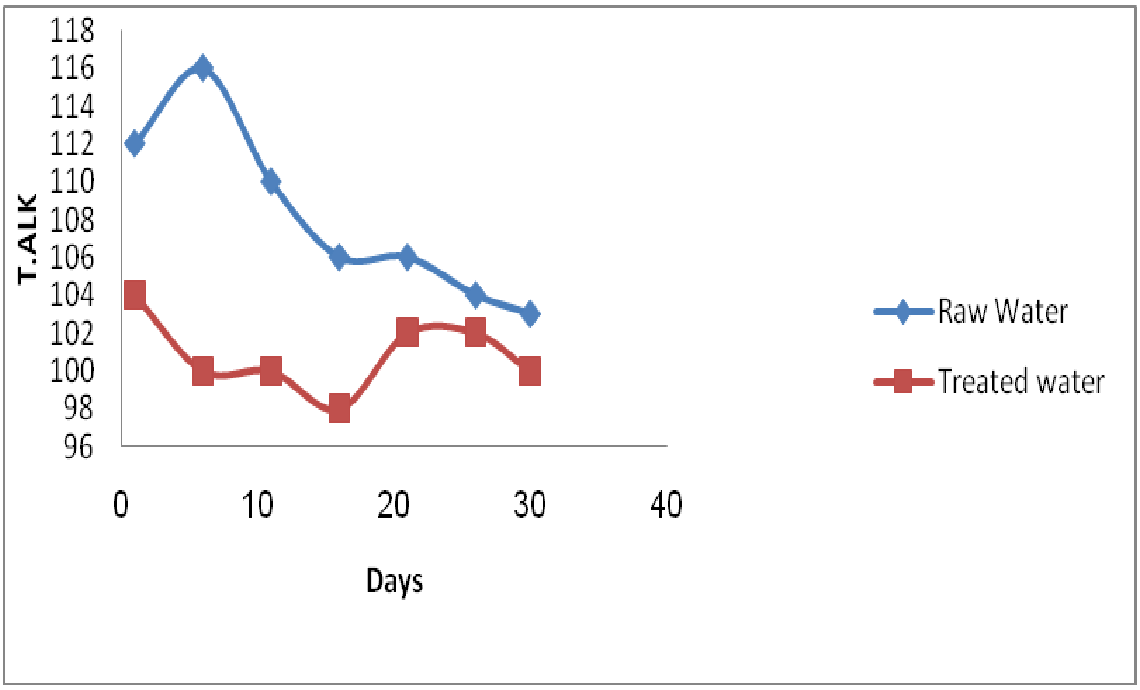

Fig (4.38): Total Alkalinity of the raw and treated water at Alshajra plant in August.

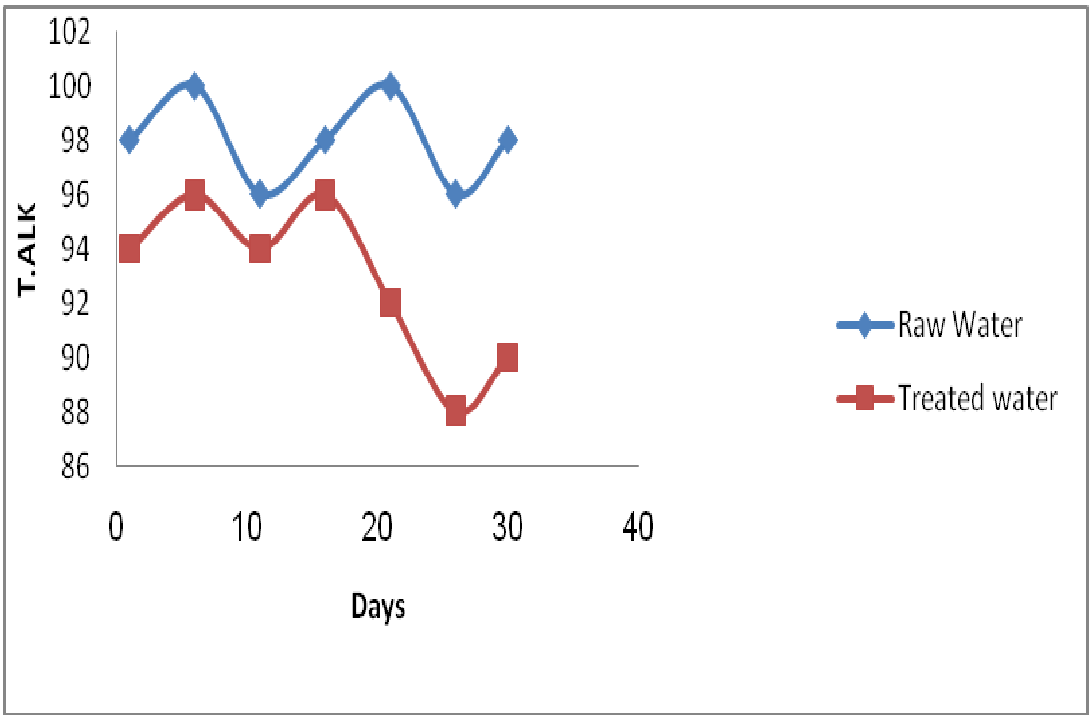

Fig (4.39): Total Alkalinity of the raw and treated water at Alshajra plant in September.

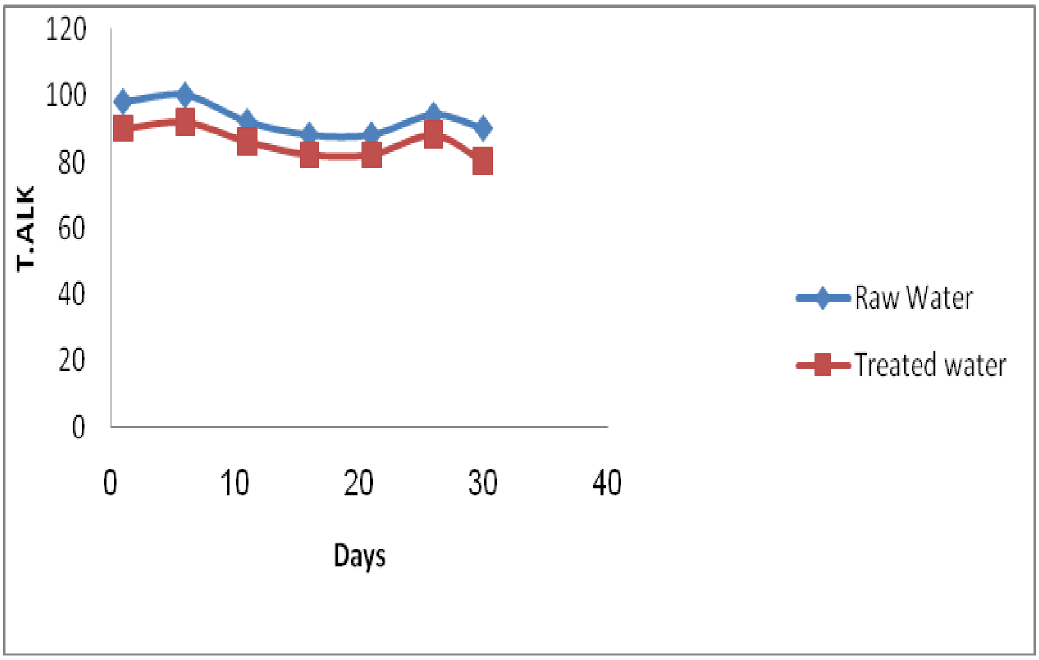

Fig (4.40): Total Alkalinity of the raw and treated water at Alshajra plant in October.

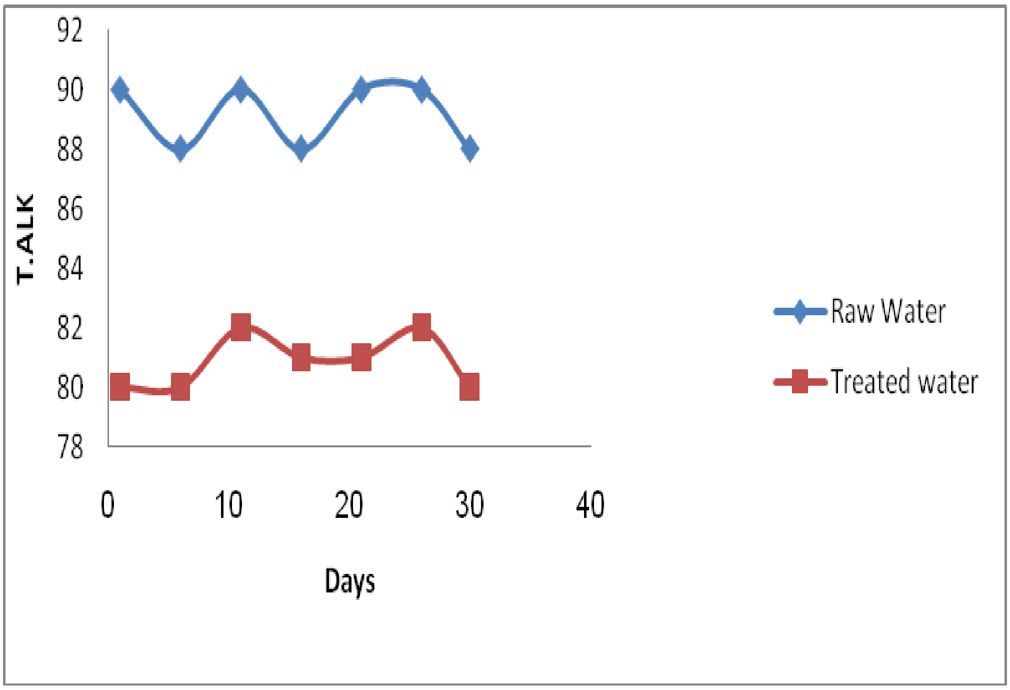

Fig (4.41): Total Alkalinity of the raw and treated water at Alshajra plant in November.

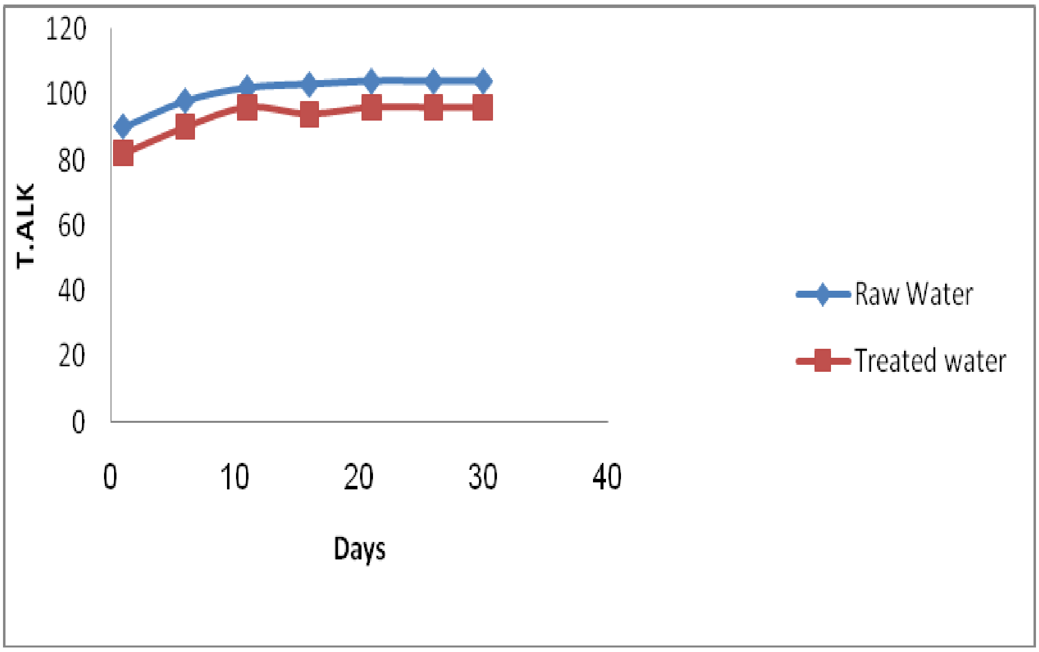

Fig (4.42): Total Alkalinity of the raw and treated water at Alshajra plant in December.

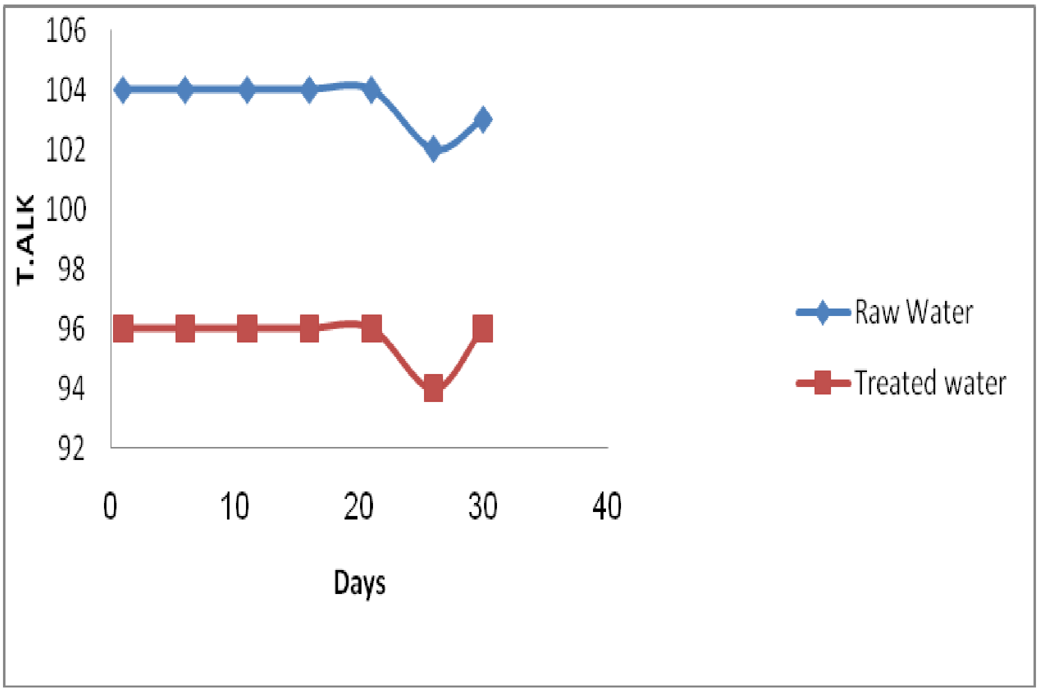

Fig (4.43): Total Alkalinity of the raw and treated water at Alshajra plant in January.

4.6.4 Jabal Awlia treatment plant:

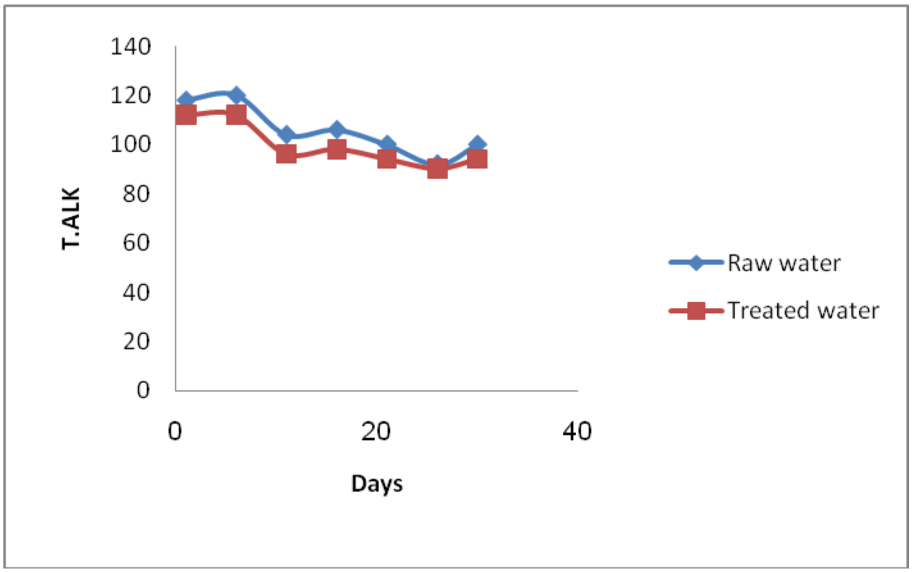

Fig (4.44): Total Alkalinity of the raw and treated water at Jabal Awlia plant in June.

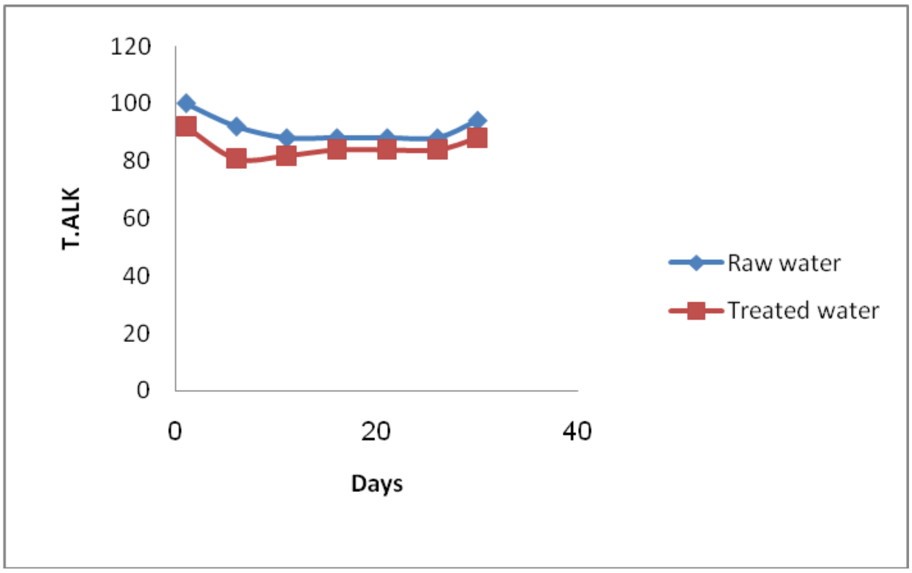

Fig (4.45): Total Alkalinity of the raw and treated water at Jabal Awlia plant in July.

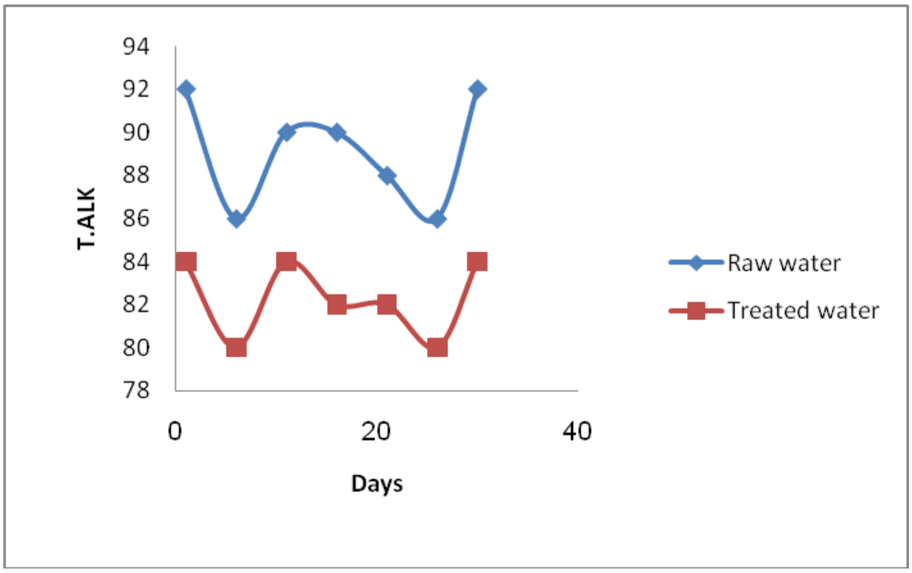

Fig (4.46): Total Alkalinity of the raw and treated water at Jabal Awlia plant in August.

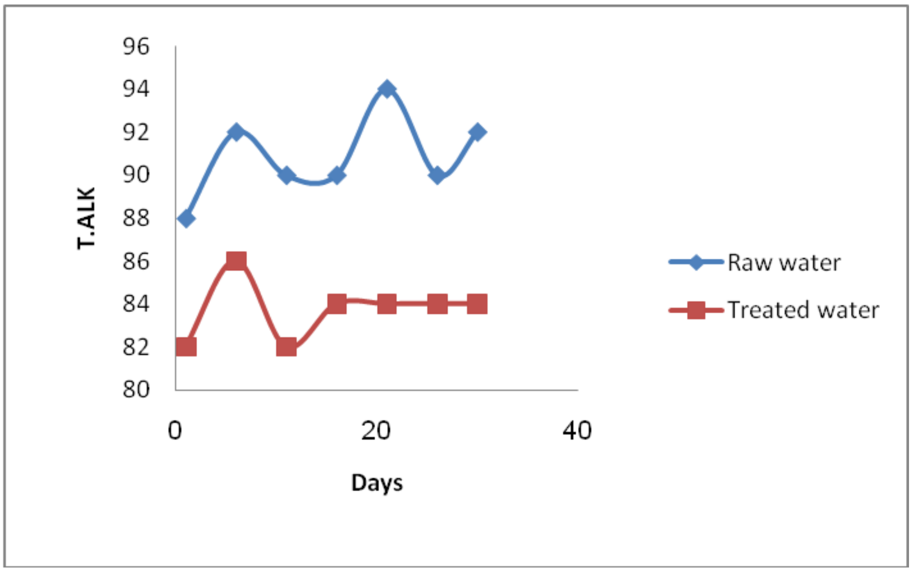

Fig (4.47): Total Alkalinity of the raw and treated water at Jabal Awlia plant in September.

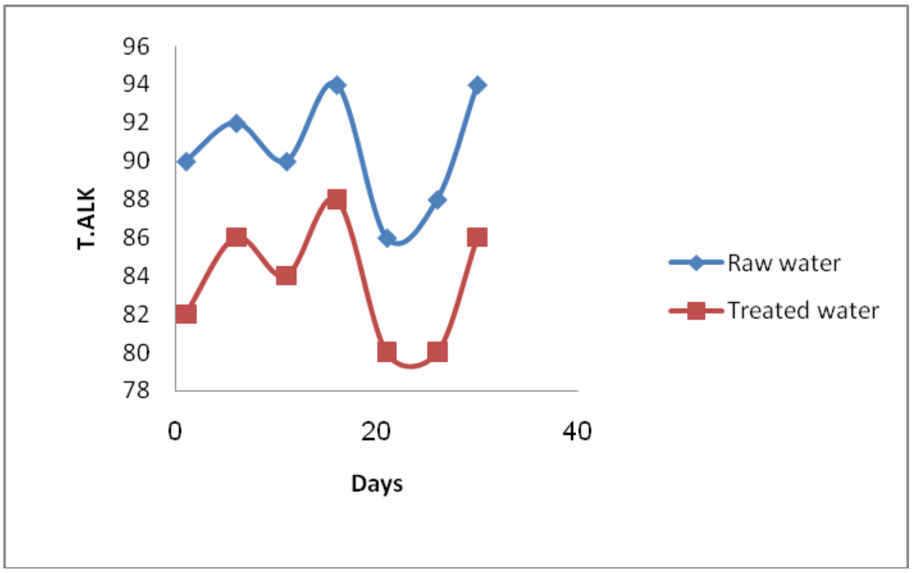

Fig (4.48): Total Alkalinity of the raw and treated water at Jabal Awlia plant in October.

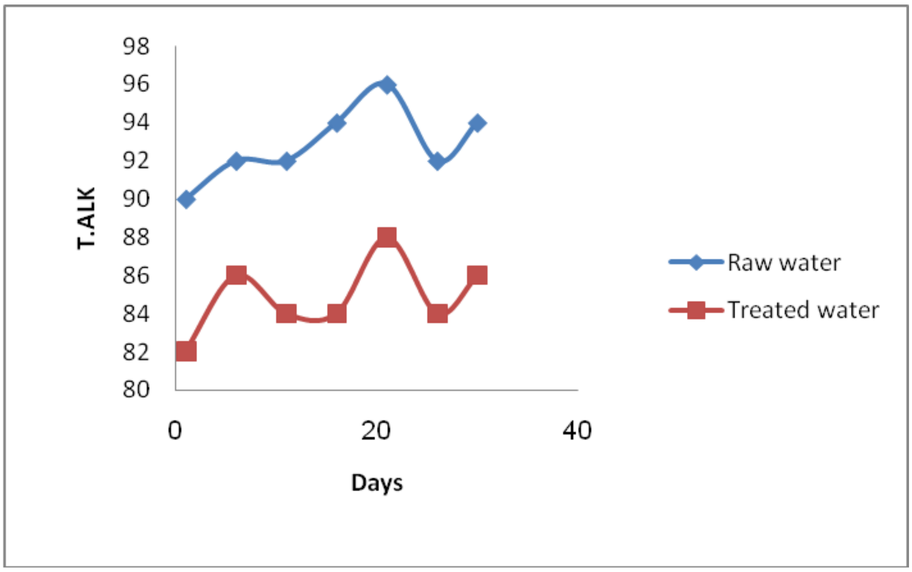

Fig (4.49): Total Alkalinity of the raw and treated water at Jabal Awlia plant in November.

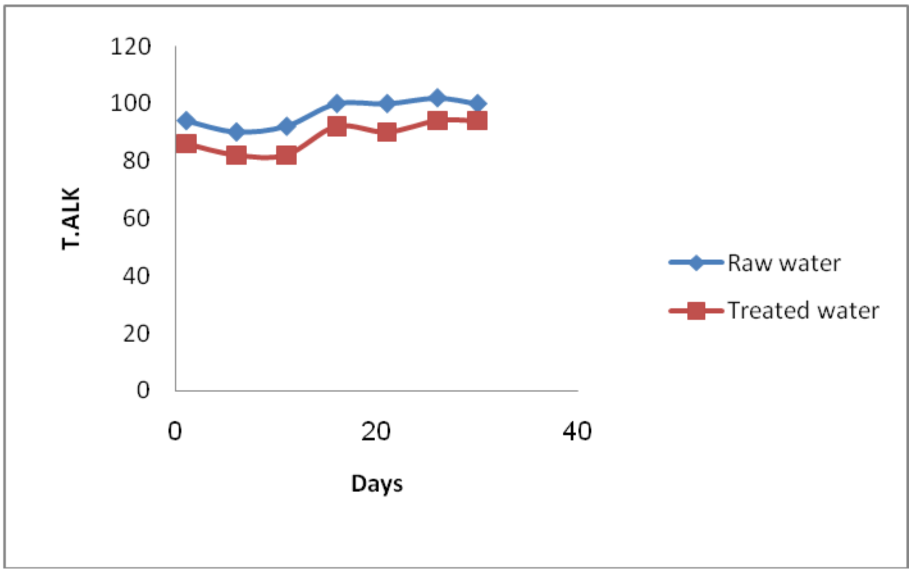

Fig (4.50): Total Alkalinity of the raw and treated water at Jabal Awlia plant in December.

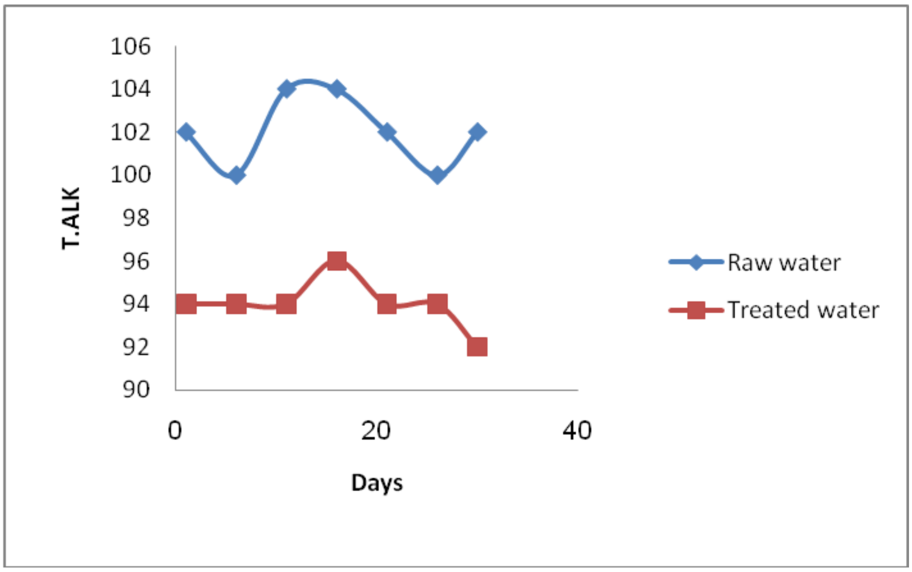

Fig (4.51): Total Alkalinity of the raw and treated water at Jabal Awlia plant in January.

4.7 The effect of treatment in pH:

Table (4.5a to 4.8b) shows the results of pH analysis. The chemical analysis shows that the pH range is (8.25 to 7.8), (10.2 to 10.4), (7.8 to 8.2), (8.2 to 8.0) for raw water, while ranged from (7.7 to 8.1), (8.3 to 8.0), (7.0 to 8.0), (7.7 to 7.8) for treated water at Mogran, Bahri, Alshajra, Jabal Awlia treatment plants respectively. All samples investigated satisfy the Sudanese standard for water quality.

4.7.1 Mogran treatment plant:

Table 4.5a: Water quality results for pH in raw and treated water at Mogran plant.

DAYS	June		July		August		September	
	pH(IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)
1	8.0	8.0	8.0	7.9	7.9	7.8	8.1	7.8
6	7.9	7.8	8.0	7.9	7.6	7.9	8.0	7.9
11	7.8	7.7	7.9	7.8	8.0	7.9	8.0	7.9
16	8.1	8.0	8.2	7.8	8.0	7.9	8.0	8.0
21	8.1	8.0	8.0	7.8	8.0	7.8	8.0	7.8
26	8.1	7.9	8.0	7.8	8.0	7.8	7.9	7.8
30	8.0	7.8	8.0	7.8	7.9	7.9	8.2	8.0

Table 4.5b: Water quality results for pH in raw and treated water at Mogran plant.

DAYS	October		November		December		January	
	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)
1	8.0	8.0	7.9	7.9	8.2	8.0	8.1	8.0
6	7.9	7.8	8.0	7.95	8.15	8.1	8.1	7.9
11	8.1	8.0	8.0	7.9	8.1	8.0	8.0	7.9
16	8.1	8.1	8.25	8.1	8.1	8.0	8.1	8.0
21	8	8.0	8.3	8.1	8.1	7.9	8.2	8.0
26	8.1	8.0	8.0	7.9	8.2	7.8	8.1	8.0

4.7.2 Bahri treatment plant:

Table 4.6a: Water quality results for pH in raw and treated water at Bahri plant.

DAYS	June		July		August		September	
	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)
1	8.0	7.9	8.2	8.0	8.1	8.0	8.2	8.0
6	8.0	7.9	8.2	8.0	8.2	8.0	8.1	8.0
11	8.0	8.0	10.4	10.2	8.2	8.0	8.2	8.0
16	8.2	8.0	8.1	7.9	12	8.0	8.2	8.0
21	8.1	8.0	8.2	7.9	10.4	8.2	8.2	8.0
26	8.2	8.0	8.0	7.9	9.0	8.0	8.1	8.0
30	8.0	8.0	8.0	7.9	8.2	8.0	8.1	8.1

Table 4.6 b: Water quality results for pH in raw and treated water at Bahri plant.

DAYS	October		November		December		January	
	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)
1	8.1	8.1	8.1	8.0	8.2	8.0	8.2	8.0
6	8.2	8.0	8.2	8.1	8.2	8.1	8.0	8.0
11	8.2	8.1	8.1	8.0	8.2	8.0	8.1	8.0
16	8.3	8.2	8.2	8.1	8.3	8.2	8.2	8.0
21	8.2	8.0	8.2	8.1	8.2	8.1	8.1	8.0
26	8.3	8.0	8.0	8.0	8.1	8.0	8.1	8.0
30	8.1	8.0	8.2	8.0	8.3	8.1	8.1	8.0

4.7.3 Alshajra treatment plant:

Table 4.7a: Water quality results for pH in raw and treated water at Alshajra plant.

DAYS	June		July		August		September	
	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)
1	8.1	8.0	8.0	8.0	7.8	7.8	7.9	7.6
6	8.0	7.9	8.0	7.9	7.9	7.7	7.9	7.7
11	8.0	7.9	7.8	7.7	8.0	7.7	7.9	7.6
16	8.0	7.9	8.0	7.7	7.9	7.6	7.9	7.6
21	8.0	7.9	8.0	7.7	8.0	7.9	7.9	7.6
26	8.0	7.9	8.0	7.4	7.9	7.6	7.9	7.6
30	8.0	8.0	7.9	7.6	8.0	7.6	7.9	7.7

Table 4.7b: Water quality results for pH in raw and treated water at Alshajra plant.

DAYS	October		November		December		January	
	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)
1	7.9	7.7	8.0	7.7	8.0	7.9	8.1	7.9
6	8.0	7.7	8.0	7.8	8.1	7.9	8.1	7.9
11	8.1	7.7	8.0	7.8	8.0	7.9	8.1	7.9
16	8.0	7.8	8.0	7.8	8.0	7.0	8.1	7.9
21	8.0	7.8	8.0	7.7	8.0	7.9	8.0	7.9
26	8.0	7.8	8.0	7.7	8.1	7.9	8.0	7.9
30	8.0	7.8	8.0	7.8	8.1	7.9	8.1	7.9

4.7.4 Jabal Awlia treatment plant:

Table 4.8a: Water quality results for pH in raw and treated water at Jabal Awlia plant.

DAYS	June		July		August		September	
	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)
1	8.1	7.7	8.2	7.8	8.1	7.8	8.1	7.7
6	8.1	7.7	8.2	7.8	8.1	7.8	8.0	7.7
11	8.2	7.8	8.0	7.8	8.0	7.7	8.0	7.7
16	8.2	7.8	8.0	7.8	8.0	7.8	8.0	7.7
21	8.2	7.8	8.1	7.8	8.0	7.7	8.0	7.8
26	8.1	7.8	8.1	7.8	8.2	7.7	8.0	7.8
30	8.2	7.8	8.1	7.7	8.1	7.7	8.0	7.8

Table 4.8b: Water quality results for pH in raw and treated water at Jabal Awlia plant.

DAYS	October		November		December		January	
	pH (IN)	pH (OUT)	Tur(IN)	pH (OUT)	pH (IN)	pH (OUT)	pH (IN)	pH (OUT)
1	8.1	7.8	8.0	7.7	8.0	7.7	8.0	7.8
6	8.0	7.8	8.1	7.8	8.0	7.7	8.1	7.7
11	8.1	7.8	8.0	7.8	8.0	7.7	8.0	7.7
16	8.0	7.8	8.0	7.8	8.1	7.8	8.0	7.7
21	8.0	7.8	8.1	7.7	8.0	7.8	8.0	7.8
26	8.0	7.7	8.1	7.8	8.0	7.7	8.1	7.8
30	8.0	7.8	8.1	7.8	8.1	7.8	8.0	7.7

4.8 Residual Chlorine:

From experimental works tables 4.9a to 4.12b show the results of residual Chlorine of investigated plants.

Mogran, Alshajra and Bahri plants often fail to meet specifications of residual chlorine in treated, while Jabal Awlia water plant often meet specifications for residual chlorine.

4.8.1 Mogran treatment plant:

Table 4.9a: Water quality results for residual chlorine at Mogran plant**.**

Days	June	Specifications	July	Specifications	Aug	Specifications	Sep	Specifications
1	0.06	lies	Nil	Lies	0.05	lies	0.25	meet
6	Nil	lies	Nil	Lies	Nil	lies	Nil	lies
11	0.57	lies	0.54	Lies	0.2	meet	Nil	lies
16	Nil	lies	0.33	Meet	Nil	lies	0.1	lies
21	0.13	lies	Nil	Lies	0.2	meet	Nil	lies
26	0.53	lies	0.75	Lies	0.1	lies	Nil	lies
30	0.67	lies	0.2	Meet	Nil	lies	Nil	lies

Table 4.9b: Water quality results for residual chlorine at Mogran plant**.**

Days	Oct	Specifications	Nov	Specifications	Dec	Specifications	Jan	Specifications
1	Nil	Not meet	Nil	Not meet	Nil	lies	Nil	Not meet
6	0.35	meet	Nil	Not meet	Nil	lies	Nil	Not meet
11	Nil	Not meet	Nil	Not meet	Nil	lies	Nil	Not meet
16	Nil	Not meet	Nil	Not meet	Nil	lies	Nil	Not meet
21	Nil	Not meet	Nil	Not meet	Nil	lies	0.1	Not meet
26	0.15	Not meet	0.3	Meet	Nil	lies	0.1	Not meet
30	0.1	Not meet	Nil	Not meet	Nil	lies	Nil	Not meet

4.8.2 Alshajra treatment plant:

Table 4.10a: Water quality results for residual chlorine at Alshajra plant**.**

Days	June	Specifications	July	Specifications	Aug	Specifications	Sep	Specifications
1	Nil	Not meet	Nil	Not meet	0.2	meet	0.2	meet
6	Nil	Not meet	Nil	Not meet	0.1	lies	0.1	Not meet
11	Nil	Not meet	Nil	Not meet	0.1	lies	0.2	meet
16	Nil	Not meet	0.15	Not meet	0.2	meet	0.2	meet
21	Nil	Not meet	0.1	Not meet	0.5	meet	0.2	meet
26	Nil	Not meet	Nil	Not meet	0.3	meet	0.3	meet
30	Nil	Not meet	0.2	Meet	0.1	lies	0.1	Not meet

Table 4.10b: Water quality results for residual chlorine at Alshajra plant**.**

Days	Oct	Specifications	Nov	Specifications	Dec	Specifications	Jan	Specifications
1	0.1	Not meet	0.1	Not meet	0.2	meet	Nil	Not meet
6	0.1	Not meet	Nil	Not meet	0.1	Not meet	0.1	Not meet
11	0.1	Not meet	0.3	Meet	0.1	Not meet	Nil	Not meet
16	0.1	Not meet	0.3	Meet	0.1	Not meet	Nil	Not meet
21	0.1	Not meet	0.2	Meet	0.1	Not meet	Nil	Not meet
26	0.2	meet	0.2	Meet	Nil	Not meet	Nil	Not meet
30	0.1	Not meet	0.1	Not meet	Nil	Not meet	Nil	Not meet

4.8.3 Jabal Awlia treatment plant:

Table 4.11a: Water quality results for residual chlorine at Jabal Awlia plant**.**

Days	June	Specifications	July	Specifications	Aug	Specifications	Sep	Specifications
1	0.5	meet	0.5	Meet	0.55	Not meet	.055	Not meet
6	0.6	meet	0.2	Meet	0.45	meet	0.3	meet
11	0.1	Not meet	0.55	Not meet	0.4	meet	0.25	meet
16	0.5	meet	0.3	Meet	0.05	Not meet	Nil	Not meet
21	0.2	meet	0.55	Meet	0.65	Not meet	0.5	meet
26	0.6	Not meet	0.6	Not meet	0.2	meet	0.1	Not meet
30	Nil	Not meet	0.4	Meet	0.25	meet	0.7	Not meet

Table 4.11b: Water quality results for residual chlorine at Jabal Awlia plant**.**

Days	Oct	Specifications	Nov	Specifications	Dec	Specifications	Jan	Specifications
1	0.6	Not meet	0.2	Meet	0.4	meet	0.2	meet
6	0.5	meet	0.5	Meet	0.6	lies	0.2	meet
11	0.6	Not meet	0.35	Meet	.05	lies	0.65	Not meet
16	0.5	meet	0.3	Meet	0.2	meet	0.25	meet
21	0.4	meet	0.35	Meet	0.2	meet	0.3	meet
26	0.35	meet	0.35	Meet	0.35	meet	0.4	meet
30	0.2	meet	0.35	Meet	0.4	meet	0.3	meet

4.8.4 Bahri treatment plant:

Table 4.12a: Water quality results for residual chlorine at Bahri plant**.**

Days	June	Specifications	July	Specifications	Aug	Specifications	Sep	Specifications
1	Nil	Not meet	Nil	Not meet	Nil	Not meet	Nil	Not meet
6	Nil	Not meet	Nil	Not meet	Nil	Not meet	Nil	Not meet
11	Nil	Not meet	Nil	Not meet	Nil	Not meet	Nil	Not meet
16	Nil	Not meet	Nil	Not meet	Nil	Not meet	Nil	Not meet
21	Nil	Not meet	Nil	Not meet	0.8	Not meet	Nil	Not meet
26	Nil	Not meet	Nil	Not meet	Nil	Not meet	Nil	Not meet
30	Nil	Not meet	Nil	Not meet	Nil	Not meet	Nil	Not meet

Table 4.12b: Water quality results for residual chlorine at Bahri plant.

Days	Oct	standard	Nov	Standard	Dec	standard	Jan	standard
1	Nil	Not meet	Nil	Not meet	Nil	Not meet	Nil	Not meet
6	Nil	Not meet	Nil	Not meet	Nil	Not meet	Nil	Not meet
11	Nil	Not meet	Nil	Not meet	Nil	Not meet	Nil	Not meet
16	Nil	Not meet	Nil	Not meet	Nil	Not meet	Nil	Not meet
21	Nil	Not meet	Nil	Not meet	Nil	Not meet	Nil	Not meet
26	Nil	Not meet	Nil	Not meet	Nil	Not meet	Nil	Not meet
30	Nil	Not meet	Nil	Not meet	Nil	Not meet	Nil	Not meet

4.9 Tests conducted during the study:

Water samples were taken from the intake and treated water reservoir from Alshajra and AlMogran plants and tested at the Central Laboratory. As shown in figure (4.13a 4.14b)

Table 4.13a: Testing result for raw water for at Alshajra plant**.**

Alshajra raw water			
parameter		**parameter**	
Appearance	Turbid	Chloride	6 mg/L
Turbidity	59.1 NTU	Fluoride	0.1 mg/L
Odor	+ ve(Algae)	Sulphate	1 mg/L
pH	8.3	Ammonia	0.35 mg/L
Temperature	26.6 ^{o}c	Nitrite	0.044 mg/L
Conductivity	201 uS	Nitrate	4.8 mg/L
TDS	131 mg/L	Iron	0.15 mg/L
T.Alkalinity	86 mg/L	Calcium	10.4 mg/L
pH.pH Alkalinity	Nil	Magnesium	6.24 mg/L
T.Hardness	52 mg/L	Sodium	17.4 mg/L
Manganese	0.012 mg/L	Potassium	6.9 mg/L

Table 4.13b: Testing result for treated water for at Alshajra plant.

Alshajra treated water			
parameter		**parameter**	
Appearance	Turbid	Chloride	16 mg/L
Turbidity	12.1	Fluoride	0.1 mg/L
Odor	+ve(Algae)	Sulphate	0 mg/L
pH	7.4	Ammonia	0.12 mg/L
Temperature	26.6 ^{o}c	Nitrite	0.016 mg/L
Conductivity	221 uS	Nitrate	2.7 mg/L
TDS	133 mg/L	Iron	0 mg/L
T.Alkalinity	78 mg/L	Calcium	10.4 mg/L
pH.pH Alkalinity	Nil	Magnesium	6.24mg/L
T.Hardness	52 mg/L	Sodium	19.5mg/L
Manganese	0.018 mg/L	Potassium	6.4 mg/L

Table 4.14a: Testing result for raw water for at AlMogran plant.

Al-Mogran raw water			
parameter		**parameter**	
Appearance	Turbid	Chloride	4 mg/L
Turbidity	5650	Fluoride	0.3 mg/L
Odor	Nil	Sulphate	12 mg/L
pH	8.0	Ammonia	0.03 mg/L
Temperature	28.2 ^{o}c	Nitrite	0.028mg/L
Conductivity	218 uS	Nitrate	8.6 mg/L
TDS	142 mg/L	Iron	0.03 mg/L
T.Alkalinity	90 mg/L	Calcium	25.6 mg/L
pH.pH Alkalinity	Nil	Magnesium	7.68 mg/L
T.Hardness	96 mg/L	Sodium	7.1 mg/L
Manganese	0.013 mg/L	Potassium	2.7 mg/L

Table 4.14b: Testing result for treated water for at AlMogran plant**.**

Al-Mogran treated water			
parameter		**parameter**	
Appearance	Turbid	Chloride	8 mg/L
Turbidity	30.7	Fluoride	0.22 mg/L
Odor	Nil	Sulphate	8 mg/L
pH	7.8	Ammonia	0.01 mg/L
Temperature	27.7 ^{o}c	Nitrite	0.025mg/l
Conductivity	220 uS	Nitrate	8.0 mg/L
TDS	143 mg/L	Iron	0.03 mg/L
T.Alkalinity	84 mg/L	Calcium	28.6 mg/L
pH.pH Alkalinity	Nil	Magnesium	7.68 mg/L
T.Hardness	96 mg/L	Sodium	7.0 mg/L
Manganese	0.016 mg/L	Potassium	2.5 mg/L

CHAPTER FIVE

CHAPTER FIVE

CONCLUSION and RECOMMENDATIONS

Based on the results of the tests performed in the laboratory of water treatment plants from 1/6/2018 to 30/1 /2019 the following conclusions were drawn:

5.1 Conclusion:

- pH of the treated water in investigated water treatment plants meet Sudanese drinking water specification of pH in the range 6.5 to 8.5.
- Total alkalinity often meets specifications and ranged between 120 and 80.
- Turbidity of the treated water does not satisfy Sudanese drinking water specifications, where the turbidity often larger than 5 NTU. High Turbidity in treated water decreases the efficiency of chlorine for disinfection.
- Residual chlorine in Bahri, Alshajra and Mogran water treatment plants out of range of specification, and meet specification in Jabal Awlia water treatment plant.

5.2 Recommendations:

- Operators must understand the basic principles and theories behind many complex water treatment concepts and treatment systems to perform their function at the highest knowledge and experience level possible.
- In the laboratory, individual staff members should be authorized to undertake procedures involving risk of any type only after appropriate training.
- All laboratories should formulate and implement a safety policy that should cover cleaning, disinfection, and the containment of hazardous substances. Safety equipment such as fire extinguishers, safety glasses, and first-aid kits should be suitably located, and readily available; they should be routinely checked and all staff should be trained in their use.
- Laboratories should be provided with the necessary equipment.
- Adequate piping with suitable sampling taps located so as to permit the collection of water samples from critical portions of the units.
- Construct pre sedimentation basin at Bahri and Mogran plants to use in the autumn to reduce the turbidity of raw water.
- Adjust the dose of PAC and chlorine to get treated water meets specifications and free of bacteriological pollution and acceptable to the consumer.
- Use remote control system (Escada) to increase follows up in plants.
- Pre chlorine should be present in plants located on the White Nile when algae abundance.

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