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Solar Energy Application for Erbil Municipal Wastewater Treatment and Reusing

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ABSTRACT

Up to now, there is no central wastewater treatment plant (WWTP) in Erbil City, Kurdistan Region Iraq. Erbil Municipal waste water (EMWW) discharges directly to the environment, or sometimes it used for irrigation, without treatment. This research focused on the EMWW characteristics, treatment using solar energy technique and reusing. Data were collected from published works since 1994 and visiting the site. Some EMWW quality parameters such as total suspended solids (TSS), chemical oxygen demand (COD), and five-day biochemical oxygen demand (BOD5) topped the effluent standards. Accordingly, treatment process like solar energy is essential. Quantity of solar energy in Erbil City is A Unit. Application of solar energy for EMWW treatment led to removal of (80-98) % of BOD, (75-95) % COD, and (85-98) % of TSS. Treaded WW is safe for irrigation. Solar energy can be used for EMWW treatment and it regards as efficient and economic technique.

ARTICLE INFO

Received: May 29, 2024
Accepted: June 26, 2024

Keywords:
Erbil
Municipal
Solar Energy
Treatment
Wastewater

DOI: 10.61186/JCER.6.2.49
DOR: 20.1001.1.2538516.2024.6.2.5.6

1. Introduction

Erbil Municipal wastewater (EMWW) comprises of domestic, industrial, commercial, washing, institutional etc. WWs. EMWW collects in the main channel near Tooraq Quarter in Erbil City, Kurdistan Region, Iraq. Due to investment projects in Erbil City, population increase, refuges and internally displaced persons (IDPs), and development of the city, tourist etc., the discharge of EMWW has been increased from 0.85 m3/s - 1.7 m3/s in 2001 to 5.56 m3/s in 2020 [1, 2]. Up to now in Erbil City, there's no principal WW treatment plants (WWTP). As a result, produced MWW from Erbil City discharges directly to the natural environment, mixes with the Greater-Zab River at Guer Area, infiltrate to groundwater, and sometimes it uses for irrigation by farmers [2,3,4]. Untreated EMWW causes problems for the environment, water sources and the population. Accordingly, treatment is crucial for the EMWW.

In literature, researchers tried to treat WWs in Erbil City. Aziz and Ali [5] treated dairy and EMWWs by using biological trickling filter. Aziz and Ali [5] published a work on quality and treatment using different methods for WWs. Industrial WW and reusing were studied by [6]. Oil

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refinery WW at Kawergosk arae treated by sequencing batch reactor and adsorption [7]. Firstly, moving bed biofilm reactor (MBBR), the sequencing batch reactor (SBR), and conventional activated sludge were designed for residential WW treatment and reusing in Erbil City [8]. But to date, there is no application of solar energy for treatment of EMWW.

Regarding solar energy application for WW treatment, Ugwuishiwu et al. [9] estimated the use of solar energy in solid waste and wastewater treatment such as in pyrolysis, solar ignition, and desalination for wastewater treatments, solar distillation, solar photocatalytic degradation, solar pathogenic organic destruction, and gasification for solid wastes treatments. Additionally, Zhang et al. [10] provided reviewed main solar based water treatment methods and technologies, and evaluated the applicability and economic and technical feasibility of various technologies in the real world. Also Guo et al. [11] investigated biomass energy and the available green energy (Solar Energy, Wind Energy, Heat Energy) that can be used in wastewater treatment plants. As a result, a comprehensive description of energy efficient technologies for wastewater treatment plants was provided. Kretschmer et al. [12] presented a new concept of adjusting the internal heat supply of (WWTP) to support the efficient usage of thermal energy and make available additional heat for (WWTP) external supply.

The current research focused on the characteristics, treatment via solar energy, and reusing of EMWW. Previously, this kind of research has not been carried out in Erbil City.

2. MATERIALS AND METHODS

2.1. Study Area and Data Collection

Erbil Province is the capital of Iraqi Kurdistan, which has a population of approximately 2 million. Erbil Province is situated in northeast Iraq. Its boundaries extend from longitude 43° 15′ E to 45° 14′ E and from latitude 35° 27′ N to 37° 24′ N. EMWW comes from domestic sewage, including wastewaters from bathrooms and kitchens, public commercial buildings and industrial regions, and storm water. All generated wastewaters from Erbil City are discharged into a valley near Turaq village, which is located at 36° 10′ 14” N to 43° 56′ 12” E and 371 m a.s.l, Figures 1 and 2. The effluent stream extends for more than 50 km, passing through several farmlands and villages, until discharging into the Greater Zab River. The quantity of discharged EMWW ranges from 0.85 m3/sec to 1.7 m3/sec [7].

2.2. Solar Energy

Solar energy is a kind of energy that is obtained from the sun. The sun acts as a fusion reactor. The continuous fusion reaction of the sun is responsible for the heat energy from which it radiates. This energy can travel infinite distances to planets millions of light-years away. The use of sunlight power for a broad range of industrial, lighting, and heating applications has been a goal of scientific researches. The exact inception date of solar energy and system science is not known.

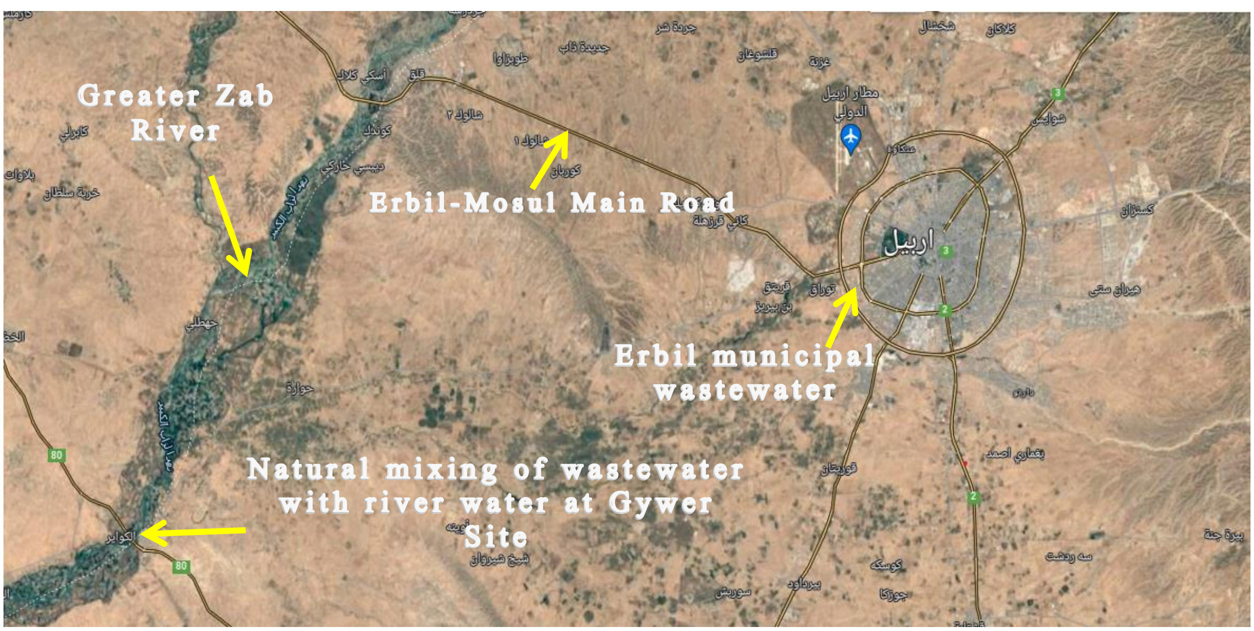

Figure 1. Satellite image (https://www.google.iq/maps/@36.1593852,43.8110409,38506m/data=!3m1!1e3

Date: December 9, 2020

Date: March 2,2021

Figure 2. EMWW main channel at Tooraq Area.

Greeks made the first attempts in the 2nd century, to explain the solar system kinematics. They developed the Ptolemaic or geocentric scheme for the solar system [13].

3. RESULTS AND DISCUSSION

3.1. EMWW Characteristics

Table 1 illustrates characteristics of EMWW in Erbil City from 1994 to 2020. It can be seen from the table some wastewaters parameters, like BOD, COD, TSS, NH_3, NO_3, NO_2, PO_4, Mg, Cd, Cu, Zn, color, Pb, Mn, oil and grease, and phenols, surpassed the principles for removal of WW. Therefore, treatment techniques are necessary earlier removal to the herbal surroundings or blending with water sources. Published works discovered that various treatment strategies which include sequencing batch reactor, adsorption, lagoons, oxidation ditch, wetland, and trickling filter had been studied for remedy of wastewaters in Erbil City [2]. Of course, every remedy approach has benefits and disadvantages. Further, preliminary cost, construction, process, and renovations are different problems of the cited treatment process. Subsequently in the extant research, treatment of EMWW via solar energy was examined. Normally, EMWW considered as weak WW [2, 5, 14].

3.2. Applied Treatment Techniques on EMWW

MSWW includes both residential and commercial wastewater, as well as wastewater discharged from industry, municipal, and similar establishments. The goal of the wastewater treatment method is to kill pathogenic microorganisms and remove or decrease toxic substances, organic and inorganic components [17, 18]. As a result, the feature of treated wastewater is improved to fulfill the criteria of WW disposal standards [2]. WW treatment commonly consists of three stages including primary, secondary and tertiary treatment (Figure 3) [19]. Removing the largest particles and organic matter happens in the primary and secondary treatment process, respectively. Then, several unfavorable substances remain in the treated water. Therefore, the tertiary treatment is applied as a polishing unit to remove these substances. These treatments usually include a combination of various biological, chemical, and physical processes. In Literature, various treatment techniques (such as wetlands, aerated lagoon, oxidation ditch, trickling biological filter, conformist activated sludge, sequencing batch reactor,

Table 1
Characteristics of EMWW from 1994 to 2020 Aziz [2].

No.	Parameter	Range	Standards
1	pH	6.1-8.85	6-9.5**
2	Temp. (ºC)	10-31.5	35**, 40*
3	EC (µs/cm)	284-2300	
4	T. Salts (mg/L)	236.8-1800	
5	TS (mg/L)	300-10000	
6	TSS (mg/L)	40-1800	60**, 35*
7	TDS (mg/L)	100-8200	
8	Turbidity (NTU)	0.41-1000	
9	Chloride (mg/L)	0.86-165	750 *
10	T. Acidity (mg/L)	0.18-60	
11	T. Hardness (mg/L)	120-590	
12	BOD_5 (mg/L)	6.3-304	40**
13	COD (mg/L)	12.2-901	100**
14	NH_3-N (mg/L)	0.004-11.4	Nil**, 1 *
15	NO_2-N (mg/L)	0.001-26	1 *
16	NO_3 –N (mg/L)	0.003-47	50**, 10*
17	SO_4 (mh/L)	0.008-1220	1500*
18	DO (mg/L)	0-10.4	
19	PO_4 (µg/L)	0.0015-6.97	3**
20	Na (%)	6.1-73	
21	SAR (%)	0.19-16	
22	otal coliform cell/100 ml X 1(	0.34-380	
23	Na (mg/L)	0.38-62	
24	Ca (mg/L)	1..8-85	
25	Mg (mg/L)	0.1-30.8	0.5**
26	Cd (mg/L)	0- 46.73	0.01**
27	Cu (mg/L)	0-18.69	0.2**
28	Zn (mg/L)	0-76.92	0.2**
29	Pb (mg/L)	0-61.76	0.1**
30	TVS (mg/L)	100-300	
31	TnVS (mg/L)	100-600	
32	BOD_5/COD	0.487-0.830	
33	Color (Pt.Co,)	186-379	Nil **
34	Mn (mg/L)	1.3-4.6	0.2 **
35	TOC (mg/L	19-180	

Continued from pervious page

No.	Parameter	Range	Standards
36	Phenols (mg/L)	0.044-0.102	0.01-0.05**
37	Oil & grease (mg/L)	0.04-1.05	Nil*, 10 **
38	ORP (Mv)	-107.4 - (-33.2)	
39	Salinity	0.26-057	
40	T. Alkalinity (mg/L)	157.3-340	
41	Alkalinity (%)	8.93-40.15	
42	TVC Bacteria (Cfu/mL)	$110*10^5$-$176*10^5$	
43	Phytoplankton density (Cells/L)	21787.5	
44	Total Bacteria Count ($X10^8$)	0.002-0.74	
45	Total bacteria cell/L x $l0^5$	0.047-193	
46	Total fungi cells/L X 10^4	0.035-240	
47	Discharge (m^3/s)	0.85-5.56	

* (EPA) Environment Protection Agency (EPA), Standards for effluent discharge, Regulations, 2003 [15].
** Iraqi Environmental Standards, Contract No.: W3QR-50-M074, Rev. No.: 03 Oct 2011 [16].

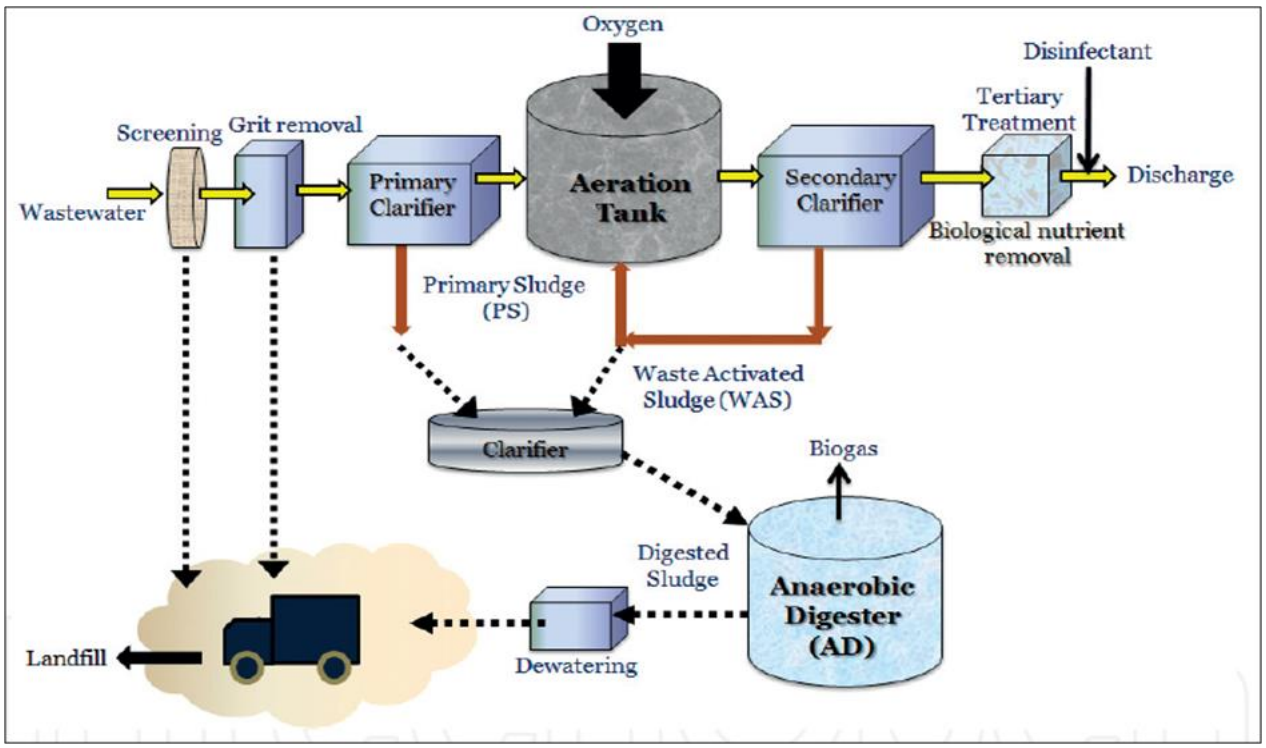

Figure 3. Typical municipal WW treatment processes Elbeshbishy and Okoye [22].

moving bed biofilm reactor, and dilution technique) were studied for treatment of EMWW [2, 8, 20, 21]. To date, treatment of EMWW using solar energy was not studied in Erbil City.

3.3. EMWW Treatment Using Solar Energy

WW treatment methods could be categorized into three groups: biological, chemical, and mechanical. They are applied in different combinations based on the concentration and type of pollutants. The most abundant renewable energy source is solar energy, which can be introduced into WWTPs. The use of solar thermal energy in WW treatment mostly consists of three aspects: (a) the solar heat is accumulated by a heat collector to improve the treatment efficiency and enhance the reaction temperature [23]; (b) In industrial WW treatment, solar thermal is being used to dewater sludge or lowering water contents of particular unique effluent [24, 25]; and (c) the solar heat can be applied for desalination and evaporation of specific wastewater in industrial WW treatment [26].

3.3.1. Solar Distillation and Desalination of WW

Water distillation is a common physical or mechanical separation technique that is obtained through condensation and evaporation processes. Solar distillation includes using solar energy to obtain distillation. A solar collector in simple solar water stills traps the solar radiation and converts it to heat. Then it is applied to evaporate the water contained in the distillation chamber of the still. As a result of saturation in the chamber, the evaporated water condenses on the trapping side. On this side, the condensed water goes through a funnel-shaped hopper to the distillate storage tank. Solar distillation can be applied to make salty water potable [9].

3.3.2. Photoelectric or Photovoltaic (PV) Energy

Solar PV power generation is a technique to convert light energy into electric energy using semiconductor materials. Solar energy conversion efficiency improvement and the decreasing the solar panel cost, PV can be used more. Various WWTPs apply PV to supply electricity to the treatment plant due to their aeration tanks [27].

Solar energy disinfection mostly employs ultraviolet (UV) rays of sunlight for killing bacteria in wastewater. It should be noticed that PV power generation mostly employs visible light. Therefore, some WWTPs combine PV power generation with UV disinfection. In artificial solar wetlands that are powered by solar heat or PV, wastewater is discharged into the wetland for biological and physical treatment [28].

3.3.3. Photocatalytic energy (UV)

Another usage of solar energy in WW treatment is using solar UV radiation for photocatalytic oxidation. Photocatalysis is the combination of catalysis and photochemistry. It is a procedure that catalysis and light is applied to accelerate or promote a chemical reaction at the same time. It can be defined as the acceleration caused by the catalyst of a light-induced reaction [29]. Photocatalysis appears as a great tool for final treatments of samples including persistent organic pollutants. The view of a typical solar photo Reactor is shown in Figure 4.

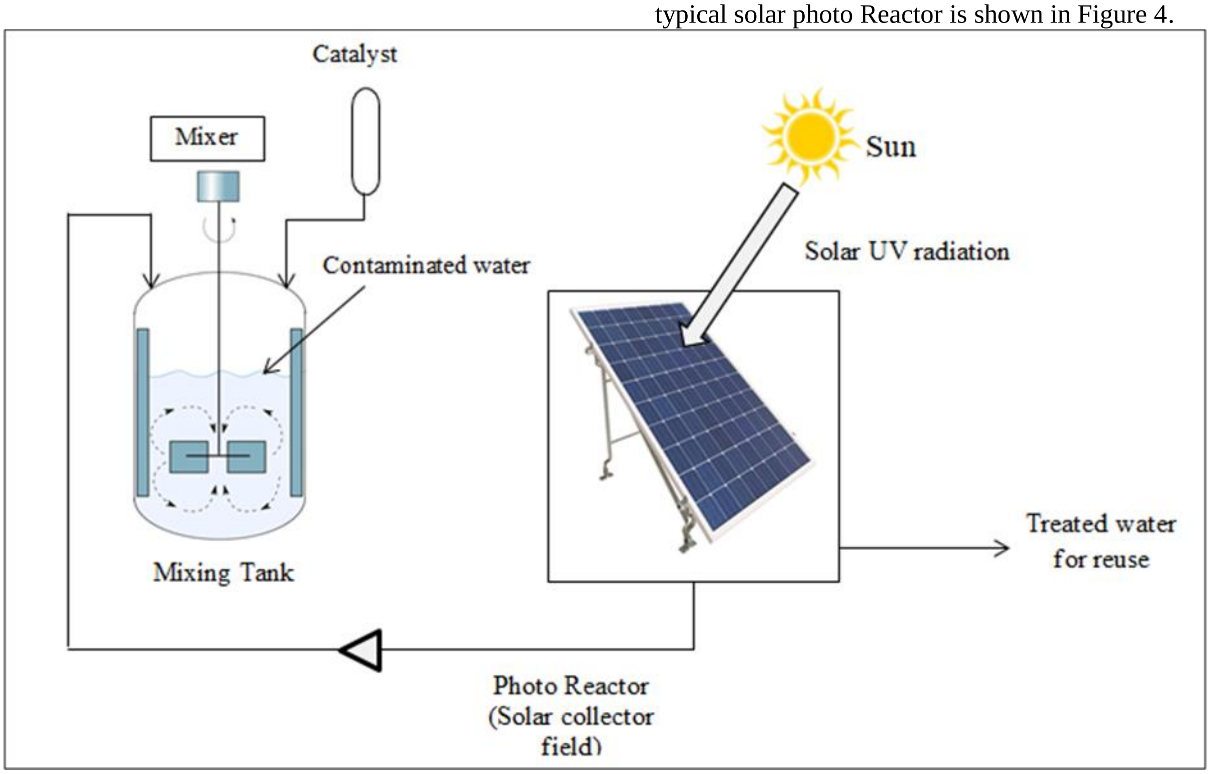

Figure 4. solar photocatalytic plants for the treatment of wastewater taken from Ugwuishiwu et al. [9].

Table 2.
WW treatment by solar energy process

No.	Type of WW	Removal Efficiency (%)	References	years
1	grey water	80 – 90 %	Mahdi et al. [30]	2021
2	WW containing chlorophenol	91 %	Jbari and Abderafi [31]	2020
3	Municipal WW	60 – 90 %	Sun et al. [27]	2019
4	Municipal WW	87 %	Sacco et al. [32]	2018
5	Municipal WW	80 %	Gurung et al. [33]	2018
6	Sewer WW	80 %	Vaccari et al. [34]	2018
7	Municipal WW	85 - 99 %	Taha and Al-Sa'ed [35]	2017
8	Municipal WW	84 %	Xu et al. [36]	2017
9	Municipal WW	79.5 %	Yan et al. [37]	2017
10	Sewer WW	56–72 %	Ni et al. [38]	2016
11	Winery WW	80 %	Velegraki and Mantzavinos [39]	2015
12	Municipal WW	96 %	Shen et al. [40]	2015
13	subsurface agricultural drainage water	85 %	Stuber et al. [41]	2015
14	Olive mill WW	87.3 %	Michael et al. [42]	2014
15	Synthetic wool dying WW	75 - 79 %	Hernandez- Rodriguez et al. [43]	2014
16	Municipal WW	75 %	Sobańtka, and Rechberger [44]	2013
17	Municipal WW	97 %	Mo and Zhang [45]	2013
18	Municipal WW	93.5 %	Chae and Kang[46]	2013
19	Municipal WW	35 - 77 %	Sousa et al. [47]	2012
20	Drinking water with pesticides spike	90 %	Fenoll et al. [48]	2012
21	Municipal WW	85 %	Miranda-Garcia et al. [49]	2011
22	Commercial azo dye Solution WW	80 %	Zayani et al. [50]	2009

3.3.4. WWs treatment by solar energy process

In literature, solar energy was applied for treatment of various types of WWs. Table 2 illustrates WWs treatment by solar energy process.

3.4. Application of solar energy for EMWW treatment

Kurdistan's geographical function on this planet gave it the proper state of affairs concerning the sun's electricity

Table 3.
Results of WW treated by solar energy system Mahdi et al. [30]

Parameters	Concentration before treatment mg/l	Concentration after treatment mg/l	Concentration range for irrigation mg/l
Chemical oxygen demand (COD)	900-1330	30-90	100
Biochemical oxygen demand(BOD_5)	270-390	11-30	40
Total nitrogen (TN)	50-65	5-9	
total natural carbon (TOC)	170-200	10-30	19-180
Ammonia (NH_3)	40-45	Nil	5
total suspended solids (TSS)	310-380	Nil	30-60

potential. The province located between 34° 42’ N and 37° 22’ N latitudes, which is highly rich in solar energy and utilizing solar energy applications reduce the dependence on fossil fuels and protects the environment from pollution and keeps it clean [51]. Solar energy capacity for the place may be evaluated via way of means of annual sun radiation as the common for Kurdistan place is 6318.83 MJ/ m2 / year and equal to 1755.23 kWh/m²/year, which is ‘4.81 kWh/m²/day’ [52].

In the last years a research has been published in Iraq and they have benefited from solar energy for WW treatment, like Mahdi et al. [30] consider the overall performance of recycling solar-powered grey water treatment machines for the intent of irrigation, used to reduce the quantity of waste grey water and decrease power intake and decrease the fees of constructing huge-scale water treatment plants. Maximum efficiency values got at the stages treatment are COD (90%-97%), BOD5 (89%-97%), TOC (80%-94%), and TN (84%-92%) and the concentration of pollution materials before and after treatment are shown in Table 3, that’s why they appear that this system will reuse almost 70% of the water that can be released into the drains that can be utilized after being treated for irrigation, car wash, and in bathrooms.

3.5. Reusing

WW reuse after proper treatment can successfully help resolve the emergency situations that may occur in areas with inadequate water resources. Industrial, municipal, and household drains can be recycled. Reuse is permitted, provided that complete environmental safety is ensured (without harm to the existing cultural plants, soil, and ecosystem), and that any health hazards to the local population are eliminated. This needs strict adherence to existing health and safety regulations and also current laws for agriculture and industry [53]. Generally, reusing municipal WW can be categorized as indirect and direct reuse. Direct reuse of treated wastewater for drinking water is not currently a viable option because of health risks. Indirect reuse is using treated wastewater after returning it to natural water sources (i.e. aquifer, lake, and river) for dilution and purification. It consists of natural buffers for further spatial and temporal separation of treatment [54].

Investigators described that Erbil City’s wastewater became now no longer secure for all kinds of irrigation earlier than treatment. They found that EMWW is proper for cooked vegetables and for irrigating green areas and [3]. Also, Aziz et al. [6] investigated on fresh wastewater samples had been gathered from Yörüksüt Dairy Factory and Erbil Steel Company and evaluated for 21 water pleasant parameters like COD, BOD5, TSS, etc. were surpassed the standards for removal of wastewater. Therefore, treatment methods are vital for the previous disposal of wastewater to the surroundings or the use for irrigation objectives. Assembled at the functions of the wastewaters, the treatment methods together with primary, secondary and tertiary have been examined. Also, the great of uncooked wastewater samplings and suggested handled business wastewater have been in comparison with the irrigation recommendations (WHO, 2005) so it can be suitable for irrigation aim. Additionally, Aziz [2] aimed to study features variants of EMWW, suitable treatment the usage of separate methods, and the suitability of the handled wastewater WW for disposal to the herbal surroundings or use for irrigation objectives. Treatment of EMWW the usage of each number one gadgets and wetland brought about elimination performance of 94.75 %, 93.07 %, 89.47 %, 96.72 %, and 57.68 % for BOD5, COD, NH3-N, TSS and PO4, respectively which resulted the disposed discharges features to be within WW criteria. Hence, handled EMWW may be used for cooked greens and watering inexperienced areas.

3.6. Sustainably and Management of EMWW

Waste management and sustainably are the procedure and practice or the administration of activities that provide for the disposal, treatment, processing, transfer, transportation, storage, separation, and collection of waste [55]. The generation of waste cannot be totally eliminated; neither can waste recycling be achieved completely. So there is always the need for waste management. The concept of waste management becomes very important because of the need to prohibit the contact between waste and humans and protect the immediate environment and safeguard community, families, and individual health. Suitable management of waste adds to the aesthetic value of the environment which is very vital for psychological, social and emotional well-being. The concept of waste management is highly dependent on the form of waste. Many researches have been done on sustainably and management in Iraq for WW, for instant Mustafa et al. [56] assessed the sustainability of the amount and great of water reassess for Erbil City and maintain security and steady primarily based totally on the evaluation with the usual limitations. In addition, Omran et al. [57] demonstrated that the sustainability of wastewater treatment is directly associated with the four dimensions in Iraq (technical, economic, social, environmental). Also, Alanbari and Muter [58] by using software programs designed to assess environmental sustainability indicators for any WW treatment plant.

4. CONCLUSION

This research highlights using of solar energy WW treatment as in Photovoltaic (PV) Energy, photocatalytic energy (UV), solar desalination and distillation for WW treatments. The application of solar energy in the management of WW guarantee the water availability for different industrial and agricultural goals and decreases pathogenicity through deactivating disease causing organisms in water for domestic purposes.

EMWW contains parameters such as BOD_5, COD, TSS etc. surpassed the WW disposal standards. Accordingly, Treatment is crucial before disposal to the environment, water resources, or reusing. EMWW regarded as weak WW. Solar energy method was effectual in removal of (80-98) % of BOD_5, (75-95) % COD, and (85-98) % of TSS. It is economic and easy method for treatment and reusing EMWW.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgement

The authors would like to acknowledge Salahaddin University-Erbil for providing the grant of the research grant to conduct this work.

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