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BOLU ABANT İZZET BAYSAL UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
Department of Mechanical Engineering

TECHNICAL AND ECONOMICAL STUDY OF WATER PUMPING AND TREATMENT SOLAR SYSTEM DESIGN

MASTER OF SCİENCE

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BOLU, ARALIK - 2023

APPROVAL OF THE THESIS

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MOHAMMED ABDULATEEF JABER JABER

ABSTRACT

TECHNICAL AND ECONOMICAL STUDY OF WATER PUMPING AND TREATMENT SOLAR SYSTEM DESIGN
MSC THESIS
MOHAMMED ABDULATEEF JABER JABER
BOLU ABANT IZZET BAYSAL UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
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This study presents a technical and economical analysis of an independent pumping and treating water simulated system that has been arranged by using PVsyst software. This system which depends upon the combination of the well's water and the solar panel's energy, is used to activate a purification system that uses the Reverse Osmosis system. The study tries to solve the problem of demand for usable water for daily usage in the facility, which is about 9 cubic meters per day in the place, which is located in Basra city in the southern region of Iraq but away from the city center. This thesis consists of two sections, circuit A (solar pumping section) and Circuit B (reverse osmosis section). Circuit A; with the electric energy obtained from solar panels, water is obtained directly from the well and sent to the tank without the need for energy storage, however circuit B, the energy obtained from PV panels is stored by batteries and operated at certain times of the day. The tests were on three different wells with different static levels(10, 20, 30 m) with different tilt angles of PV panels (15, 30, 45˚). After making the simulation processes for each well it shows that 10 m static level and 45 deg system efficiency and return of investment is 75.2% and 523.5% in a row well, However, 20 m static level well and 45 deg system efficiency is 65.9 % and return of investment is 496.9 %, at the same time 30 m static level with 45 deg system efficiency 79 % but the return of investment 470 %.

KEYWORDS: Solar Pumping, Renewable Energy, Solar Radiation, Deep Well, RO System, PVsyst, Water Treatment, Economic Evaluation.

ÖZET

SU ARITMA VE POMPALAMA SİSTEMİ İÇİN GÜNEŞ ENERJİ KULLANIMININ TEKNİK VE EKONOMİK ANALİZİ
YÜKSEK LİSANS TEZİ
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BOLU ABANT İZZET BAYSAL ÜNİVERSİTESİ
LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ
MAKİNE MÜHENDİSLİĞİ BÖLÜMÜ
(TEZ DANIŞMANI: DOÇ. DR. KADİR GELİŞ)

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Bu çalışma, PVsyst yazılımı kullanılarak düzenlenen bağımsız bir su pompalama ve arıtma simülasyon sisteminin teknik ve ekonomik analizini sunmaktadır. Kuyu suyu ile fotovoltaik panel enerjisinin birleşimine dayanan bu sistem, ters osmoz sistemini kullanan bir arıtma sistemini devreye sokmak için kullanılır. Çalışma, Irak'ın güney bölgesindeki Basra şehrinde, şehir merkezine uzak bir yerde bulunan bir tesiste günlük yaklaşık 9 metreküp olan kullanılabilir su talebi sorununu çözmeye çalışmaktadır. Bu tez iki bölümden oluşmaktadır; Devre A (güneş enerjisi pompalama bölümü) ve Devre B (ters ozmoz bölümü). Devre A; Güneş panellerinden elde edilen elektrik enerjisi ile enerji depolamaya gerek kalmadan doğrudan kuyudan su alınıp depoya gönderilir ancak devre B'de pv panellerden elde edilen enerji akülerde depolanarak günün belirli saatlerinde çalıştırılır. Testler, farklı statik seviyelere (10, 20, 30 m) ve PV panellerin farklı eğim açılarına (15, 30, 45 °) sahip koşullarda, üç farklı kuyu üzerinde yapıldı. Her bir kuyu için simülasyon işlemleri yapıldığında 10 m statik seviyeli ve 45 derecelik sistem verimliliği ve yatırım geri dönüşünün %75,2 ve sıralı kuyuda %523,5 olduğu, ancak 20 m statik seviyeli kuyu ve 45 derecelik sistem verimliliğinin %65,9 olduğu görülmektedir. yatırımın geri dönüşü %496,9, aynı zamanda 30 m statik seviyede 45 derece sistem verimliliği %79 ancak yatırımın geri dönüşü %470'dir.

ANAHTAR KELİMELER: Solar Pompalama, Yenilenebilir Enerji, Güneş Radyasyonu, Derin Kuyu, RO Sistemi, PVsyst, Su Arıtma, Ekonomik Değerlendirme

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LIST OF ABBREVIATIONS AND SYMBOLS

GW: Giga WATT

PV: Photo Voltaic

PPM: Per Part Million

GHG: Greenhouse gas

SPWPS: Solar-Powered Water Pumping Systems

PVWP: Photo Volatic Water Pumping

NREL: National Renewable Energy Laboratory

SAM: System Advisor Model

PVPMC: Photo Volatic Performance Modelling Collaborative

RO: Reverse Osmosis

BC: Before Christ

KWp: Peak Kilowatts

CSP: Concentrating Solar Thermal Power

MW: Mega Watt

POA: Plane of Array Irradiance

NSRDB: National Solar Radiation Database

TMY: Typical Meteorological Year

WHO: World Health Organization

WWTPs: Wastewater treatment plants

RESs: Renewable Energy Sources

SSE: Surface Meteorology and Solar Energy

TDS: Total Dissolved Solids (ppm)

HRES: Hybrid Renewable Energy Sources

H: Head (m)

SDD: Specific Drawdown (m/m^3 /h)

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1. INTRODUCTION

1.1 Literature Review.

Renewable energy is a top priority work to solve the world's energy issue means that the world is in the midst of an energy crisis (1), as a result of factors such as rising populations, greater demand for energy, and continuous reliance on oil. Companies, organizations, households, and educational institutions employ renewable energy sources to offset the carbon emissions from their use of fossil fuels(2).

To keep the average global surface temperature below 2 degrees Celsius, a worldwide energy shift is required. Technological progress, especially in the energy industry, will make this shift possible(3). The record-breaking increases in installed renewable energy capacity can be attributed to the competitiveness and rapidly decreasing prices of renewable energy (4). The timing and magnitude of energy shifts are notoriously hard to predict. It takes about 50 years for a change in energy to go from complete market penetration to complete dominance, according to historical data (5).

Some of these are the ProAlcool program in Brazil (which began in 1975), the Energiewende in Germany, the climate targets in Denmark, and the 32 percent binding target set by the European Union for 2030(6). The renewable energy goals of several countries are continually increasing. More than half of the 94 GW of new solar PV capacity added worldwide this year may have come from China. To optimize employment, study, technology, and energy security, the Russian Federation is speeding up the adoption of solar and wind energy through auctions(7).

Lack of access to sufficient energy supplies is a serious concern worldwide, especially in developing countries. The need for energy is growing rapidly in developing countries because of their expanding economies and populations. The African continent has the fastest-growing population in the world (8). The production and use of energy accounts for 80% of carbon dioxide emissions and two-thirds of total global greenhouse gas emissions (9). In 2016, the average amount of carbon dioxide in the atmosphere was 400 parts per million, or 40 percent greater than during pre-industrial times(10).

In recent decades, emerging economies, led by China and India, have become the largest contributors to greenhouse gas emissions(11). This is due to the fact that standard Coal, oil, and natural gas are used to keep up with the ever-increasing need for energy. Producing 42% of global emissions, When it comes to energy-related carbon dioxide emissions, the power sector is the biggest offender (12). Pollutants like SO_2 and NO_x cause problems on a global scale, including acid rain and premature death(13). Fuels can have less of an impact on the environment if the power industry modifies how they are used(14). In terms of long-term power supply, photovoltaics an endless, pollution-free energy source are indispensable.

In contrast to solar thermal power plants, which convert solar radiation into high-temperature heat to supply thermal or electrical energy, solar photovoltaics (PVs) directly use sunlight to generate electricity (15). Improved energy security, reduced poverty and greenhouse gas emissions, and solutions to regional and local environmental issues are all possible thanks to solar energy-based technologies. (16) . While the cost of oil and gas fluctuates, the price of solar and wind power systems has plummeted considerably over the past 30 years and is still declining (17), which means those renewable energy sources that can store the cleanest, efficient, and inexpensive power(18). The fundamental barrier to the effective integration of large amounts of renewable energy is the non-dispatchability of systems based on renewable energy(19).

Integration of renewable energy sources in advanced sustainable buildings appears to be a viable choice, and the importance of cool thermal energy storage in this context was discussed. In contrast, cool thermal energy storage shows promise as a game-changer for peak load management and the elimination of renewables' intermittent nature(20).

The amount of solar energy that reaches Earth's continents each year is more than 200 times greater than the amount of commercial energy that humans consume in a year(21). By the end of the next decade, solar panels could cost half as much as they do today, making solar energy a viable alternative to more conventional energy sources (22). Solar power can be split into two categories. The first use light from the sun to heat a space, while the second uses electricity Indirectly and directly, passive solar energy harnesses the sun's thermal energies. Structures can only make indirect use of energy (or) (23). Thermal (for heat engine or process heating), photochemical (photovoltaic), and photophysical uses of solar radiation are all possible (photosynthesis) (24). Photovoltaic (PV) cells convert sunlight into electricity directly.

Examined the transition from fossil fuels to a solar PV hybrid system and conducted a techno-economic analysis of the system's potential impact on the efforts to develop a sustainable energy infrastructure(25).The technical and financial viability of integrating solar collectors with low-volume organic Rankine cycle devices (26). The findings support the limited use of such devices in residential settings, particularly in colder climates(27). Study the readiness of households to pay for and take part in off-grid solar PV adoption in Lagos, Nigeria, as well as its impact on the long-term development of new communities. Recent studies suggest that photovoltaic technology could be used to generate electricity from solar energy cleanly and sustainably (28). Solar energy has the potential to improve power grid voltage quality(29).

Heating systems in residential structures often benefit from the addition of solar panels(30), powering solar desalination systems, and integrating into existing district heating infrastructure(31), when combined Humans need about 5 liters of pure water per day. using vapor-compression and -adsorption cooling systems (32), as well as the heat supply for agricultural solar dryers products (33). It’s clear to see, attitudes about solar water pumping systems have shifted positively over the globe. Five liters of clean water per person per day is the minimum amount considered necessary for subsistence (34). This presented a problem for delivering water to remote areas that lacked ready access to a national grid station (35).

Water pumps that run on electricity can be directly fueled by the sun using photovoltaic panels. Scientists have spent a considerable amount of time trying to perfect solar-powered water pumping systems (36). Figure 1.1 depicts SPWPS installations from all across the globe solar-powered water pumping systems are gaining importance in remote, rural, and unserved areas where it is difficult or expensive to maintain grid connectivity.

Factors such as distance from the national grid for electricity transmission and inadequate mobility contribute to the rapid expansion of the rural energy sector.

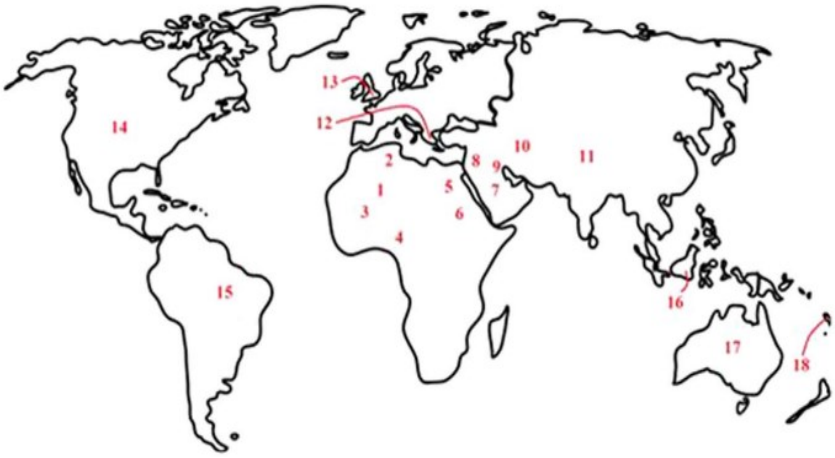


Figure 1. 1 . depicts areas where solar water pumping devices have been built (SWPS) (150)

The development of PV water pumping systems aids in the growth of the rural economy (37). In the long run, solar pumps save money compared to diesel pumps performed a preliminary study on the potential for (38), conducted research to determine the viability of independent PV pumping system (39), and designed for Mediterranean greenhouse irrigation (40). Where conventional energy sources are either nonexistent or excessively expensive, such SPWPS have proven useful in India for irrigating tiny applications and satisfying minor drinking water demand (41). Researchers looked at the feasibility of using the PVWP system for purposes other than water pumping (42).

The safety of a PVWP system designed to supply drinking water to a house was evaluated after it had been installed (43). A 130 m^3 storage tank was filled with water thanks to the technique. The desalination procedure also makes use of SPWPS(44). The mining industry makes extensive use of solar-powered water pumps(45). When designing a solar pumping system, PVsyst software is a crucial simulation tool a Geneva-developed virtualization platform that facilitates analysis of photovoltaic (PV) system performance metrics (46). Independent and grid-connected systems can be constructed with it (47). Multiple charts and reports are generated by the simulation for the PV system. The results can be seen in the software, sent to another application, or stored for further review (48).

The results can be displayed monthly, daily, or even hourly and can include many variables from the simulation. The "Loss Diagram" predicts problems with the design of a system(49). System sizing refers to the procedure of determining the voltage and current ratings of each component of a standalone system needed to supply the load(50). One such PV simulation tool is the System Advisor Model (SAM). The National Renewable Energy Laboratory (NREL) in the United States of America is responsible for developing the SAM software)(51). The PV Quality Management Estimation Collaborative (PVPMC) and Sandia National Laboratories in the United States developed and maintained the simulation tool PVlib (52).

1.2 Aim and Scope of The Study.

This study covers the topic of the lack of potable water in Basra province in Iraq, especially the southern portion of the province, which is the supposed location of this study and where an industrial facility located distant from the city has a workforce of engineers, logistical supporters, technicians, and workers, this facility requires a quantity of clean and drinkable water for daily usage, which costs the company 16425 $ per year which is 328500 $ according to the water prices at the Iraqi market, for 20 years that is the presumed study period so the study will.

- Work to find the solution to the water lack by utilizing renewable energy sources, through the design of an autonomous plant for pumping and treating water with a Reverse Osmosis treatment system, that is powered by solar panels, which is a combination of underground water and a renewable energy source.

- Examine the system's technical and economic aspects that will work in an area that has an aquifer with static level between 10 m to 30 m, changing the tilt angle of solar panels that activate the pumping part by the range of (15, 30, 45) deg for each static level to find out what are the affections of each angle on the system such as (system power, unused PV power, number of pumps, energy at pump, pumped water, number of PV modules used, pump efficiency, system efficiency, initial cost, return of investment)

2. THEORETICAL BACKGROUND AND FUNDAMENTALS

2.1 Solar Before Photovoltaic.

Since the dawn of time, people have considered using solar energy to heat water. The ancient Greeks built their houses in the fifth century B.C. so that they might use the sun's warmth in the winter. Swiss physicist Horace de Saussure developed the first practical solar collector for heating water in the 1760s—a glass-topped, insulated rectangular box. The solar energy technology used today was developed by inventors and businesspeople in Europe and the United States in the nineteenth century(53). In 1839, while experimenting with an electrolytic cell consisting of two metal electrodes, Edmund Becquerel discovered the photovoltaic effect(54).

August Mouchet, a French mathematician, received funds from the French government to develop a renewable energy source, and in 1878, he constructed a solar-powered steam engine. In 1878, at the World's Fair in Paris, Clarence Kemp used parabolic dish collectors to construct the first solar steam-powered plant. This method of creating solar energy is still employed today, even though the French government did not offer extra funds (55). Between 1880 and 1914, Scientific American published approximately fifty articles on the topic of solar energy, demonstrating the widespread interest in its possibilities during the ensuing decades. In the 1890s, when California had plenty of sunshine but no coal, several solar water heater enterprises were established.

In 1891, Clarence Kemp developed the Climax solar water heater by enclosing his water tanks in a pine box with a glass front. Around 1600 of these heaters had been sold by the year 1900 in southern California. An ex-mechanical engineer at Carnegie Steel named William J. Bailey developed a solar thermal collector in 1908 (56). He separated the solar water heater's heating element, which was outside, from the insulated storage tank, which was within the house. The Solar Motor Company of Boston was founded in 1892 by British immigrant Aubrey Eneas(57).

He used Mouchot's conical reflector to generate more steam from the boiler by heating it more evenly. After relocating the Solar Motor Company to Los

Angeles in 1903, Eneas ramped up his efforts to promote his products throughout the region. The huge cone collectors were not designed to withstand the severe and unpredictable local weather, unfortunately(58). Eneas gave up on solar power in the end because he realized it was too expensive. The gas-powered water heaters developed by Eneas and Bailey in the 1920s were first only used in Florida. Within a few short years, most residences in Miami had solar water heaters after construction business owner Bud Carruthers established the Solar Water Heater Company there (59). The company's prosperity, however, was short-lived, and it collapsed in 1926.

2.2 Photovoltaic Technology.

The photovoltaic module is a type of technology that converts nutrients into electricity without using an acceptor. They are easy to operate and maintain, and they generate substantial results from relatively modest inputs. Photovoltaic cells generate electricity by converting light into chemical energy as shown in Figure 2.1(60). Solar systems frequently make use of semiconductors including monocrystalline silicon, polycrystalline silicon, microcrystalline silicon, copper indium diselenide, and cadmium telluride.

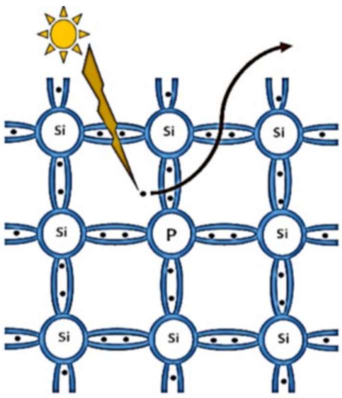


Figure 2. 1. *n-Type silicon free electron*
(60)

Numerous structures, electronic devices, electrical connections, and mechanical devices are used to regulate and control PV systems to maximize their operational efficiency and produce the maximum amount of electricity from the system's cells, modules, and arrays(61).

The maximum amount of power an inverter can send out while the sun is directly overhead is measured in peak kilowatts (KWp). Since 2002, PV device development has been ongoing to increase efficiency, and the industry is now a rapidly expanding one, with annual growth rates exceeding 100%. Grid field insulation, which can be installed on the ground or the roof, improves the efficacy of a PV system's ability to provide light. The capacity of PV systems is between 10 and 60 MW, and they must be correctly branded to indicate capacity and durability.

A well-designed PV panel may operate efficiently for up to 10 years at 90% capacity and 25 years at 80% capacity, however, this varies greatly depending on service and loading. Its efficiency varies depending on several factors, including the weather and, especially, the amount of sunlight it receives(62). As a result, numerous avenues of inquiry have been pursued in the quest for a reliable, constant source of energy.

2.3 Wells.

A water well is any artificially created underground aquifer from which potable water can be drawn. Water may spontaneously flow to the surface while the well is excavated, creating what is known as a flowing artesian well. However, the majority of the time, water must be pulled from the well. Wells often have the form of vertical shafts, but they can also be horizontal or slanted. Bank filtration, in which surface water is collected by recharging it via sediments in riverbeds into horizontally positioned wells either beneath or beside the stream, makes extensive use of horizontally positioned wells. Horizontal shafts dug by hand in the highlands of the ancient Persian Empire (modern-day Iran) are the Qanats, the world's oldest wells(63).

The complexity and high cost of well drilling and construction for geothermal direct-use projects are rarely considered (64). This section will introduce the reader to the tools and methods necessary to dig and complete a geothermal well. The data supplied here is meant to help architects, engineers, and consultants with tasks like creating specifications, finding qualified contractors, and keeping an eye on the drilling and finishing stages. Drilling direct-use geothermal wells can typically make use of tried-and-true methods and tools for water well drilling. Although there are exceptions with higher temperatures and flow, most of these wells produce water at temperatures below the boiling point and with no natural flow at the surface. While sophisticated safety gear like blowout preventers is rarely necessary, the well-being of the public and the drilling crew still must be guaranteed. Cementing's importance to the well's structural stability is often underestimated. Loss of productive zones, intrusion of cold water or geothermal water into undesirable zones, and premature well failure can all result from improper cementing. The importance of proper cementing cannot be stressed in light of rising worries about the movement between different zones and the potential contamination of freshwater aquifers.

2.4 Drilling Methods.

2.4.1 Cable Tool.

Since conventional drills rely on power rotation, cable tool drilling offers an alternative. Instead, a hefty piece is lifted and dumped onto the formation numerous times to crush and break it apart. Figure 2.2 depicts a cable tool rig used for this procedure, which has the advantage of being able to drill through a variety of formations, such as vast crevices and caves, that would otherwise be difficult to access. Drilling with a cable tool is slower than using other methods. In this method, the pitman arm and spudder beam move the cable and drill bit up and down along a narrow drill line. Because of the twist in the cable, the bit is always striking an opposing face(65).

On the upstroke, you can tighten the tool connections by pulling on the left-lay cable. Boreholes are bailed out when water is pumped into them to generate a slurry. The casing is not necessary while drilling in consolidated formations, however, in the event of a cave-in, driving clamps attached to the tools are used to drive casing equipped with a drive shoe to the formation's base. Additional casing-enclosed sections are drilled to continue the operation. To drop the bit into the well, the casing's inside diameter must be bigger than the bit's. The hole gets bigger as the casing is driven in, and if further drilling is required, a smaller casing can be added. Around the casing, bentonite slurry is used to lubricate the casing, seal any leaks caused by pressure variations, and keep unconsolidated material in place(66).

Cementing water well casings to the borehole wall, often to a competent formation, is a legal requirement in most jurisdictions. Cementing the geothermal zone is a common practice in geothermal wells to keep the water hot and prevent the fluids from mixing with the surrounding freshwater. Before or while cementing, any temporary casing must be removed.

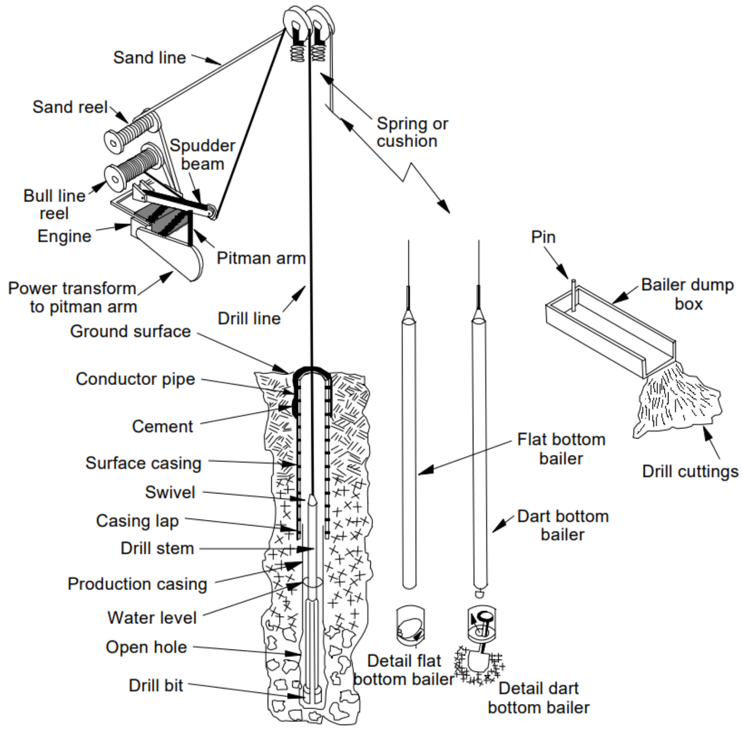


Figure 2. 2. Cable tool drilling method (65)

2.4.2 Rotary Drilling.

Rotary drilling is the most common technique for both water and geothermal wells, and it has both benefits and drawbacks. Figure 2.3 depicts a typical rotating mud rig, which uses a hollow drill collar and drill pipe to rotate the drill bit, which is commonly a tri-cone roller. The rotary table and kelly are used to apply the torque. Cuttings are removed from beneath the bit, cooled, and carried to the surface by drilling fluid that is pumped down the drill pipe and emerges from apertures in the bit. The bit is weighed down by the drill collar assembly, and the drill pipe is held taut by the moving block(67).

The drilling process can be slowed down in certain formations due to insufficient cleaning action at the drilling face if too much force is applied to the bit. However, top-head drive rigs do not employ a rotary table and kelly. The drill pipe receives its torque supply directly from the mast via a hydraulic motor that moves up and down the mast. These rigs have pull-down chains for working at lower depths and use shorter, lighter collars. Top head drives are capable of drilling most direct-use wells, although they are smaller than huge conventional rotary table rigs. Masts and draw works on certain rigs can lift 150,000 pounds, and their drives can generate 140,000 inch-pounds of torque(68).

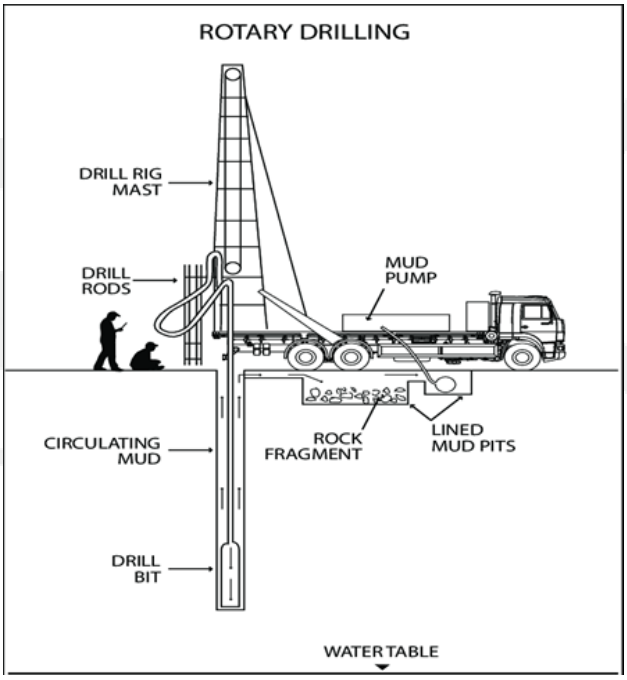


Figure 2. 3. Rotary drilling method (151)

2.5 Water Static Level

The level of water in a well at any one time while no pumps are running is known as its "static water level." When the well has not been pumped for a set period before the measurement, the result is more accurate (69). Because of the potential for inaccurate readings, it is crucial that the static water level not be monitored immediately after pumping. An electric sounder or profundity scale, a soaked tape, or an airplane are all viable options for measuring a water level at rest.

2.5.1 An Electric Sounder or Electric Depth Gauge.

The best method to keep track of water levels in wells is to use an electric sound wave or depth gauge. An ammeter indicates a closed circuit when a weight is attached to an insulated wire with level markings. A small 9 or 12-volt battery powers the circuit until the wire is submerged in water, at which point the battery automatically shuts off. The driver retrieves the length from the water to the top of the cap on the line by lowering the wire or listening line until the needle deflects. The depth is determined by first marking the starting position on the casing, and then measuring the distance between the two marks with a regular tape measure(70).

2.5.2 Wetted Tape.

Up to around 90 feet, water levels can be measured accurately using the wetted tape method. Knowing how deep you think the water is in the well ahead of time is crucial. In this method, the length of a steel measuring tape of exactly one hundred feet establishes the value of a lead weight. Before taking a measurement, the final eight to ten feet of tape are dried and smeared in the carpenter's chalk. Drop the tape into the hole until the specified area is completely submerged. The operator lines up a reference point, such as the top of the casing, with a whole foot mark on the tape. After the tape is removed, the wetted mark can be interpreted. Taking the mark at the top of the casing and subtracting it from the mark at the wetted mark yields the true depth from the top of the casing to the water level (71).

2.5.3 Air Line.

For wells deeper than 300 feet, the airline method is seen as the most effective for repeated testing. Using this method requires lowering a pipe or tube with a narrow diameter from the well's surface to a depth of roughly 20 feet below the predicted water table. The pressure inside the line is equalized with the pressure exerted by the depth of water outside the line by evacuating excess air from the end of the line. This method is typically used with 14-inch steel or plastic pipe or quarter-inch copper or brass tubing. The exact length of the airline is determined when it is being set up in the well. The operator ensures an airtight well casing by securing the airline in a vertical position, preventing it from spiraling inside the casing. It has been securely attached to the pump column at the designated spot. The lowest point of the airline is submerged while the pump is operating at full capacity (72).

2.6 Specific Water Drawdown.

typically used to describe the drop in depth (in feet or meters) that occurs when water is pumped from a well (73). It is essential to monitor the drawdown to make sure your water supply is sufficient and protected. Information gathered for drawdown might reveal whether or not your water supply is slowly dwindling. If this is discovered promptly, it can be used to plan for and implement water conservation measures or to seek funding for a new water supply. You may learn a lot about your wells' efficiency and productivity by monitoring their drawdown.

A well's efficacy and efficiency can be evaluated by combining drawdown data with well yield. Additionally, drawdown measures aid in early problem identification. By comparing well-yield data with exact drawdown measures, issues like encrusted screens and pumps that need adjusting can be spotted. Drawdown measurements may be mandated by local ordinances or regulatory bodies. Drawdown tests, along with other quality checks like pH and alkalinity testing, may be required regularly by some regulatory agencies. Check the local laws to make sure everything is in order.

The efficiency of your wells and the rules in your area will determine how often you need to check your drawdown. While some states require regular testing, others let the well operator decide. Wells with adequate water output, rapid recovery, and little drawdown may only need to be checked quarterly. However, other wells might need to be watched round-the-clock. There are three stages in the drawdown calculation process (74).

2.7 Well-Casing Selection and Installation.

Borehole walls are protected by casing, contaminants are kept out of the well's water supply, and water can be pumped up or injected back down the well through the casing. Whether composed of PVC or stainless steel, it needs to be higher than any predicted flood levels or have a watertight seal. The advantages of plastic casing are portability, simplicity of installation, long service life, and protection from corrosion. In exceptional cases, less typical encasing materials may be employed. The casing should be placed with care, especially in subsidence- or shift-prone locations(75).

There are several criteria that go into choosing the appropriate well casing size.

1 The maximum flow capacity of a well is often set during construction based on current demands rather than anticipated growth.

2. Dimensions of the pump apparatus, such as the bowl and motor diameters, dictate the size of the pump house casing

3. Multiple casings may be required to segregate undesirable zones due to geological and aquifer factors; smaller-diameter casings and screens may be installed below the pump. In such situations, it is crucial that casings fit snugly and be well sealed.

4. Depending on the manner of installation, several casing diameters and combinations may be used.

5. For better alignment and plumpness, larger casing sizes may be recommended under difficult drilling conditions.

6. In terms of water quality, adopting a casing diameter that is too small runs the risk of future pump blockages due to clogging and corrosion.

7. The choice of case size may also be affected by the presence of other devices, such as water-level transducers (76).

2.8 Water Treatment.

At first, it was crucial to guarantee that the water supply was free of harmful microorganisms like Escherichia coli. Various physical and chemical characteristics are included in the World Health Organization's (WHO) strict guidelines for safe drinking water. As more was learned about the dangers of chemicals in water and as analytical technology improved, stricter regulations were enacted to protect the public(77).

There is a widespread belief in Europe's water business at the moment that the ever-growing number of standards and analyses requires more efficient administration. There is thus a movement away from analyzing as many variables in water resources. Instead, risk assessments and water safety strategies would be used to determine whether individual cases require investigation of additional characteristics.

In theory, any body of water might be purified into potable water. However, there are constraints on the water quality that can be properly handled in a practical sense. Besides financial considerations, factors such as ecological and environmental limits and aesthetic concerns can prevent people from tapping into certain water sources. Although exceptions have been made, such as at Windhoek, Namibia, since the late 1960s, direct reuse of wastewater as drinking water is generally regarded as unsuitable at this time.

Different treatment techniques can be used depending on factors including the nature of the raw water supply, the amount of space available for construction, the cost of operations and initial investment, and the preferences of the individual or business (78). Keep in mind that there may be more than one effective method of water treatment that can be applied to any given water supply. The necessity to improve current facilities is a common restriction placed on engineers, limiting their options for new processes.

This chapter divides the topic of water purification into three sections: the past, the present, and the potential future. It also briefly touches on water reuse and various treatment methods used in underdeveloped countries. Processes are subjectively placed into these categories based on the writers' age and level of experience, but they do give a useful way to organize the diverse approaches. In reality, water providers try to deliver the safest water possible at the lowest possible cost, while also taking into account and reducing any potential dangers. To solve certain problems, it is sometimes necessary to use both conventional and cutting-edge methods of treatment. An increasing focus on risk management is required as some organizations and nations may prefer to take a chance on falling short of quality requirements than pay more to ensure that they are met(79).

2.8.1 Traditional Water Treatment.

The following are the broad categories into which conventional water treatment methods fall. Conventional water treatment often entails a number of the following stages when dealing with surface waters:

1. Catchment management is the process of regulating the environment from which water is drawn.

2. Water is stored in a building called a "raw water storage" before it is cleansed.

3. Screening, sometimes known as "sieving," is a method of separating materials by size.

4. Allowing particles to settle to the bottom of a container is called sedimentation.

5. Aeration, or the addition of air to water, is often used to treat groundwaters that contain excessive amounts of iron (80).

6. Dosing chemicals into water as part of its purification process.

7. Coagulation and flocculation, are defined: as encouraging the aggregation of minute particles for more manageable disposal.

8. Water is filtered slowly through layers of sand to remove any leftover contaminants.

9. Quickly filtering water using gravity to separate contaminants using fine media(81).

10. Pressure filtration, in which water is pushed through a filter medium by pressure, is frequently employed for groundwaters as well.

11. Chlorination refers to the process of adding chlorine to water to kill bacteria and is often used to treat groundwater.

12. Chlorine contact tank: letting water spend enough time in touch with chlorine to prevent contamination.

13 Filter wash water can be recycled by allowing sediments to settle to the bottom of the tank and then utilizing that water for other purposes.

14. Lagoons are used for the disposal of the sludge that is produced during the treatment process.

15. Sludge dewatering is the process of removing excess water from sludge before it is disposed of.

Groundwater with elevated amounts of iron and manganese is a common source of difficulty. As a result, these factors are typically prioritized by groundwater treatment plants. The procedures are more commonly utilized for surface water treatment than they are for groundwater(82).

2.8.2 Modern Water Treatment.

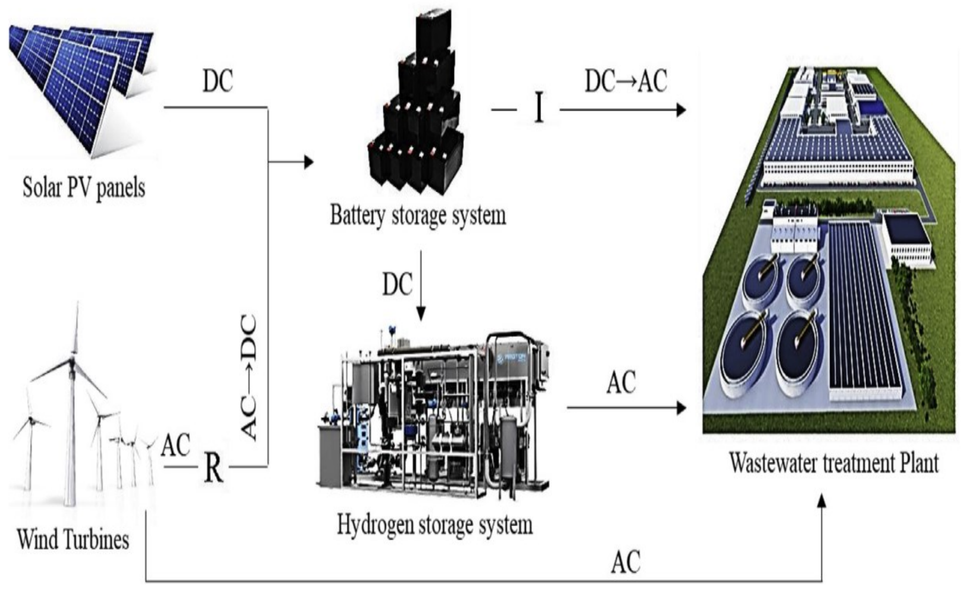
Due to high energy demand and GHG emissions, the wastewater treatment plant (WWTP) industry is currently unsustainable. Energy conservation is essential for long-term sustainability because WWTPs account for 3–5% of worldwide electricity usage (83). It is crucial to acquire RESs to minimize GHG emissions and fulfill expanding energy needs, especially when aging infrastructure and tougher discharge rules contribute to increased energy demand. The clean and abundant qualities of RESs, such as PV and WT technologies, make them the most viable alternatives (84). Several nations have taken proactive steps to expand their RES infrastructure.

However, due to intermittent uncertainty, relying entirely on a single renewable energy source may be unreliable for fulfilling the dynamic power requirement of a WWTP. Hybrid renewable energy systems (HRES) that integrate several forms of energy generation have been offered as a solution to this problem. Higher dynamic energy demands can be met and the limits of single-resource systems can be overcome with the help of HRES, which integrates PV, WT, and possibly energy storage (85). Reliable scaling of HRES has been an issue despite its widespread adoption in far-flung regions due to its low upfront costs, high efficiency, and environmental fortitude.

The ideal size of HRES components must be calculated to achieve linear behavior of system components, ensure compatibility between RES and load demand, maximize capital investment, system dependability, and environmental effect (86). Several methods have been developed by researchers to deal with nonuniformity, with indicators like energy cost (COE) and loss of load probability (LOLP) taken into account. Power system reliability is an important key performance measure since distribution failures account for a considerable amount of power outages(87). Several studies have presented strategies for evaluating the practicability and techno-economic value of HRES, as well as optimizing the scale of distribution systems. The trustworthiness of such systems to fulfill ever-changing requirements, however, is frequently disregarded.

Implementing sustainable energy policy, technological development plans, and investment prioritization all require HRES analysis within the context of industrial sustainable development(88). To do so, there is a need to specify relevant indicators for choice-making procedures. Plans for the long-term viability of HRES have been offered in previous research, with consideration given to technological, economic, social, and environmental factors. Relationships between dependability, economic costs, and environmental implications have traditionally been established using multi-criteria decision-making (MCDM) techniques, such as fuzzy-set approaches. Fuzzy-TOPSIS is a smart MCDM approach that takes reliability, economic, and environmental studies into account; however, its use has not been thoroughly investigated(89).

Even in the context of wastewater treatment plants (WWTPs), holistic approaches that take into account all relevant parameters are uncommon in the field of renewable energy research. Optimal power management at WWTPs is the focus of this study, which will evaluate reliability, and economic, and environmental



assessments to respond to changing needs and cut down on energy use(90). The proposed method entails developing a perfect HRES out of photovoltaic cells, wind turbines, and batteries. Using the fuzzy-TOPSIS method, an exogenous decision-making criteria-based decision matrix is constructed. The comparison results provide useful information for power system sizing and optimization, allowing energy policy and decision-makers to create the most effective HRES possible(91).

Figure 2. 4. Combined energy water treatment system (92)

Figure 2.4. is a diagram of an HRES, showing how photovoltaic modules, wind turbines, and an energy storage system (ESS) powered by batteries or hydrogen would work together. Power is produced and stored for use by a wastewater treatment plant. The World Bank Group's data on solar radiation and wind speed is used in the system. The battery is charged using electricity, and any excess power is stored as hydrogen (92).

The generated electricity is used to power the load, and the process's water is reused. Direct current (AC) is supplied to the load, and any unused current (AC or DC) is stored in a battery. The battery's DC power can be converted to usable AC if necessary (93).A full method for determining the optimal size of an HRES in a wastewater treatment facility (WWTP). The study looked at the HRES from a variety of angles, including dependability, cost, and environmental impact, to come up with the best possible setup. The research showed the importance of these three factors in addressing dynamic power demands by examining several unbiased impact scenarios. The HRES design that resulted from using the fuzzy-TOPSIS method was deemed to be feasible, with a 20% failure rate, 932.78 tons/year of CO_2 emissions, and a cost of $264.8 million annually.

The HRES setup includes 165 PV panels and 5 wind turbines, split between DC and AC generation at a 90%:10% ratio. Insights for energy power management methods were gleaned from the study, which emphasized the advantages and disadvantages of filling supply gaps in renewable energy use. The technology employed can be used in the future with data from other renewable energy sources to achieve optimal sizing. The future functioning, dependability, economic sustainability, and environmental impact of the HRES require more research to accurately predict energy demand (94).

2.9 Reverse Osmosis System Design.

In reverse osmosis (RO), water is pushed through a semi-permeable membrane in the opposite direction of normal osmosis, thus eliminating dissolved particles and other impurities (95). One must be familiar with the natural process of osmosis to grasp the function and mechanism of reverse osmosis. Osmosis is a natural occurrence and a key process in the natural world. It's the process by which a less concentrated salt solution becomes a more concentrated one. Osmosis can be seen in the process of water absorption by plant roots from soil and by human kidneys from blood(96). See how osmosis works in Figure 2.5. below. The solution with the lower concentration will move toward the solution with the higher concentration. Consider the case of two containers:

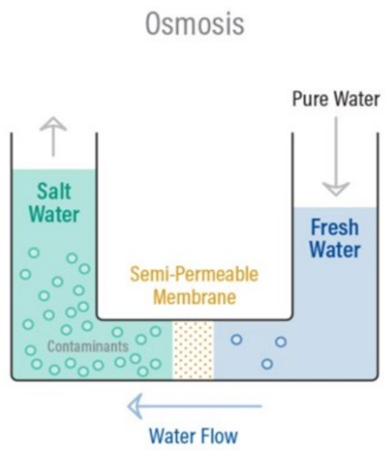


Figure 2. 5. Osmosis principle (95)

If you had two containers, one filled with low-salt water and the other with high-salt water, divided by a semi-permeable membrane, the low-salt water would start to migrate toward the high-salt container.

2.9.1 Typical Operational Parameter Ranges.

Table 2. 1. Comparison between sea and brackish water for operational ranges for key parameters in reverse osmosis (97)

Parameter	Seawater RO	Brackish water RO
RO permeate flux $(L/m^2 - h)$	12-15 (open water intake) 15-17 (beach well)	12-45 (groundwater)
Hydrostatic pressure (kPa)	5500-8000	$600 - 3000$
Membrane replacement	20% per year Every 2-5 years	5% per year Every 5-7 years
Recovery (%)	35-45	75 - 90
pH	5.5 - 7	5.5 - 7
Salt rejection (%)	99.4 - 99.7	95 - 99

Key reverse osmosis (RO) parameters and their normal operational ranges are compared for both brackish water and salt water in Table 2.1. (133). When compared to seawater RO, the parameters for brackish water RO are more flexible because the feed water contains a lower proportion of total dissolved solids (TDS). A brackish water RO membrane can produce permeate with a TDS concentration substantially below the limits specified for drinking water, even with a salt rejection rate as low as 95%(98).

Brackish water RO's lowered salt in the feed water also increases permeate flow at lower feed pressure and increases membrane longevity. If the RO supply water is excessively contaminated and not properly prepared, however, the membrane's lifespan can be drastically shortened. Furthermore, membrane fouling can have a significant effect on the RO flux, and there is a maximum flux that can be achieved with a given commercial membrane. Both RO membrane types have the same pH tolerance range, which is essential for preventing precipitation and maintaining material compatibility(99).

2.9.2 Seawater RO System Design.

Single-pass and two-pass designs are the most common for RO plants that desalinate seawater. Two-pass structures were common in the planning and construction of older plants, but the single-pass method is now generally used.

However, some plants may need as many as four rounds, and this varies based on a wide variety of design parameters and the expected quality of the generated freshwater(100). Figure 2.6 depicts the single-pass structure of the seawater RO plant at the Eni Gela site in Sicily. This plant's input water has a TDS concentration of 40,070 mg/L, and its target recovery rate is 45% (137). The three-year recovery rate fluctuated between 46% and 40%. Energy costs, feed water characteristics (temperature, composition, and total dissolved solids content), target recovery rate, and quality criteria for the generated water all play a role in determining whether passes are used (101).

The feed water pressure and flow rate are directly responsible for the majority of the energy usage in a RO system. Larger hydrostatic pressures (up to 7000 kPa) are needed to generate the necessary permeate flow from saltwater because of the high salt content. As was said before, the osmotic pressure must be lower than the hydrostatic pressure on the feed side of the membrane. The osmotic pressure on the feed side rises as the recovery rate of the RO unit increases, necessitating higher feed pressure. However, the required feed flow rises with the recovery rate (for a specific product flux). As recovery rates rise, overall energy needs drop, and vice versa for lower recoveries (35-50 percent). Therefore, depending on the salinity of the feed water, there is a minimum energy demand of 50–55 percent. An example is provided in Figure 2.7 below. The energy requirements of an RO system will increase as the pressure drops during successive passes (102).

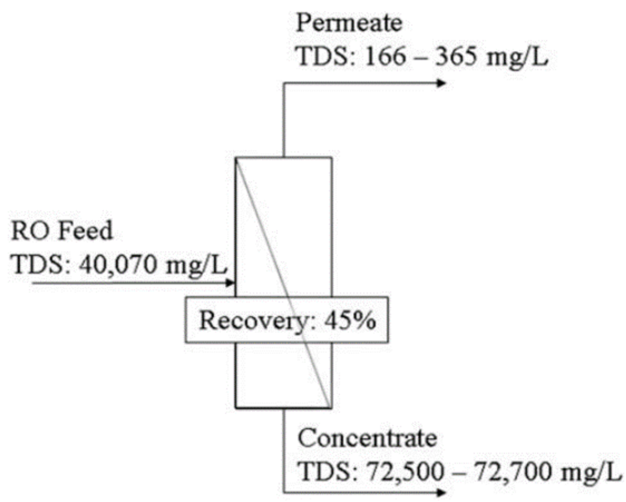


Figure 2. 6. Process flow diagram for the one-stage seawater RO (101)

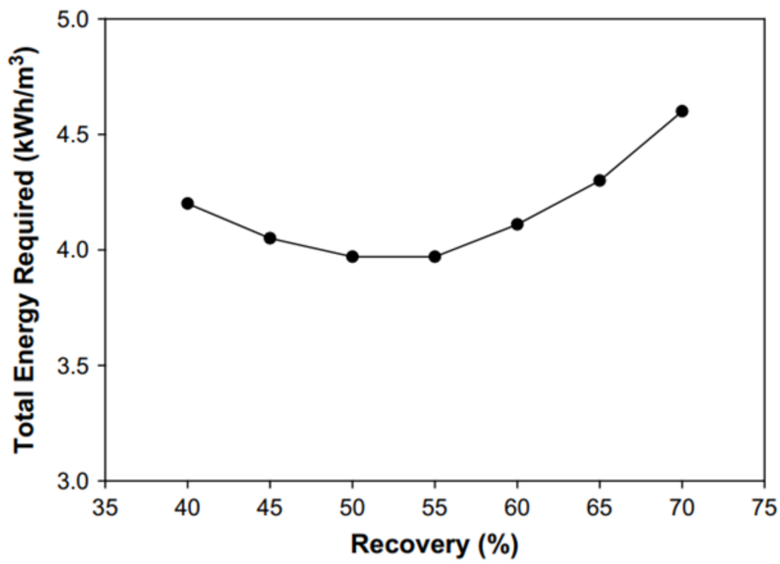


Figure 2. 7. Total energy required per volume of permeate produced as a function of RO system recovery (102)

2.9.3 Renewable Energy – Brackish Water RO System.

Brackish water was desalinated using renewable energy and RO technology. Recent research in Australia has made use of solar-powered, low-throughput RO desalination devices (0.4-1 m^3/day). Fresh water is scarce and communities are small in the middle Australian outback, thus these gadgets were put to good use there. Coastal cities' needs are met by massive RO plants, but many inland communities are running dry. Delivering potable water to remote areas has been made possible by small-scale RO plants powered by renewable energy sources (103).

Small RO systems have not been widely used in rural areas because of the high initial cost. However, if communities switch to renewable energy sources, RO technology could become more widely available. Establishing and running an RO plant in a rural community requires a thorough examination of the social aspects of water consumption, in addition to the technical considerations such as site selection and plant procedures(104).

Numerous locations in dry, sunny climates where rural populations lack access to electrical power grids or centralized water supply networks have tested solar-powered RO systems. Both marine and freshwater environments have been analyzed. The output capacity of solar photovoltaic-powered brackish water systems is anywhere from 0.1 to 60 m^3/day(105).

3. MATERIAL AND METHODOLOGY

In this section, the structure of the system and its cause of design will be explained. The lack of pure water (9 m^3 in our case) in Basra where most of it comes from tankers is causing a real problem, especially for facilities away from the city center which is causing a waste of money and time. At this point, the study depends on the mix of underground water and solar energy using an RO treatment system which is the most available and efficient. This system will be stand-alone and self-dependent using solar panels to reduce costs including installation, running, maintenance, and increasing the system lifetime.

The system in detail contains two circuits below which are.

Circuit A: this circuit consists of Five main parts starting from the solar panels which convert the sunlight into a suitable electricity flow through the solar inverter to activate pumps that are working on taking water from the well to inject it inside the water tank.

- Solar Panels
- Solar Inverter
- Pumps
- Well
- Water Tank

Solar pumping systems rely on solar energy and include components such as solar panels, solar inverters, submersible pumps, wires, and a water tank. The electrical energy obtained from the solar panels is transferred to the submersible pump using the solar inverter in the solar irrigation (Circuit A) portion, eliminating the requirement for energy storage. The flow rate of the submersible pump varies with the amount of energy produced from the solar panel and is stored at various flow rates based on solar radiation. The pump, solar panel, and solar inverter are chosen based on daily water requirements.

Circuit B: Continuously this circuit also depends on solar panels that charge batteries through the controller so those batteries are connected to a converter that feeds the RO system by electricity so it can work on the treatment of the water that comes from circuit A to make it useable water.

- Solar Panels
- MPPT Controller
- Batteries
- DC- AC Converter
- Ro Treatment System
- Workers building

In the context of the reverse osmosis system, denoted as Circuit B, the focus shifts from the initial collection of water using the solar pumping system to the subsequent purification process. Here, a designated quantity of water acquired through the solar pumping system undergoes a conversion process into usable water within specified time frames throughout the day. This transformation is facilitated by a reverse osmosis (RO) device, an integral component known for its efficacy in purifying water.

Specific calculations have been conducted to outline the operational parameters of the RO device utilized in this scenario. The study assumes the RO device to operate at a power capacity of 20 kW with an efficiency rate of 65%. These figures play a pivotal role in determining the energy requirements and the subsequent incorporation of this device into Section B of the overall system.

Interestingly, the energy needed to power the reverse osmosis system within Section B is obtained from photovoltaic (PV) panels, creating a self-sustaining loop within the larger solar-driven infrastructure. In this section, energy is stored within batteries, serving as a reservoir to facilitate the operation of the reverse osmosis system. Notably, the RO system is operational for a specific duration of 1 hour per day, optimizing the conversion of the collected water into potable or usable water resources.

This careful orchestration of energy storage and utilization ensures that the reverse osmosis system operates efficiently within the defined time frame, effectively transforming raw collected water into a clean, usable resource. The integration of solar-generated power to operate the reverse osmosis system, combined with strategic energy storage mechanisms, highlights an innovative approach to sustainable water purification processes.

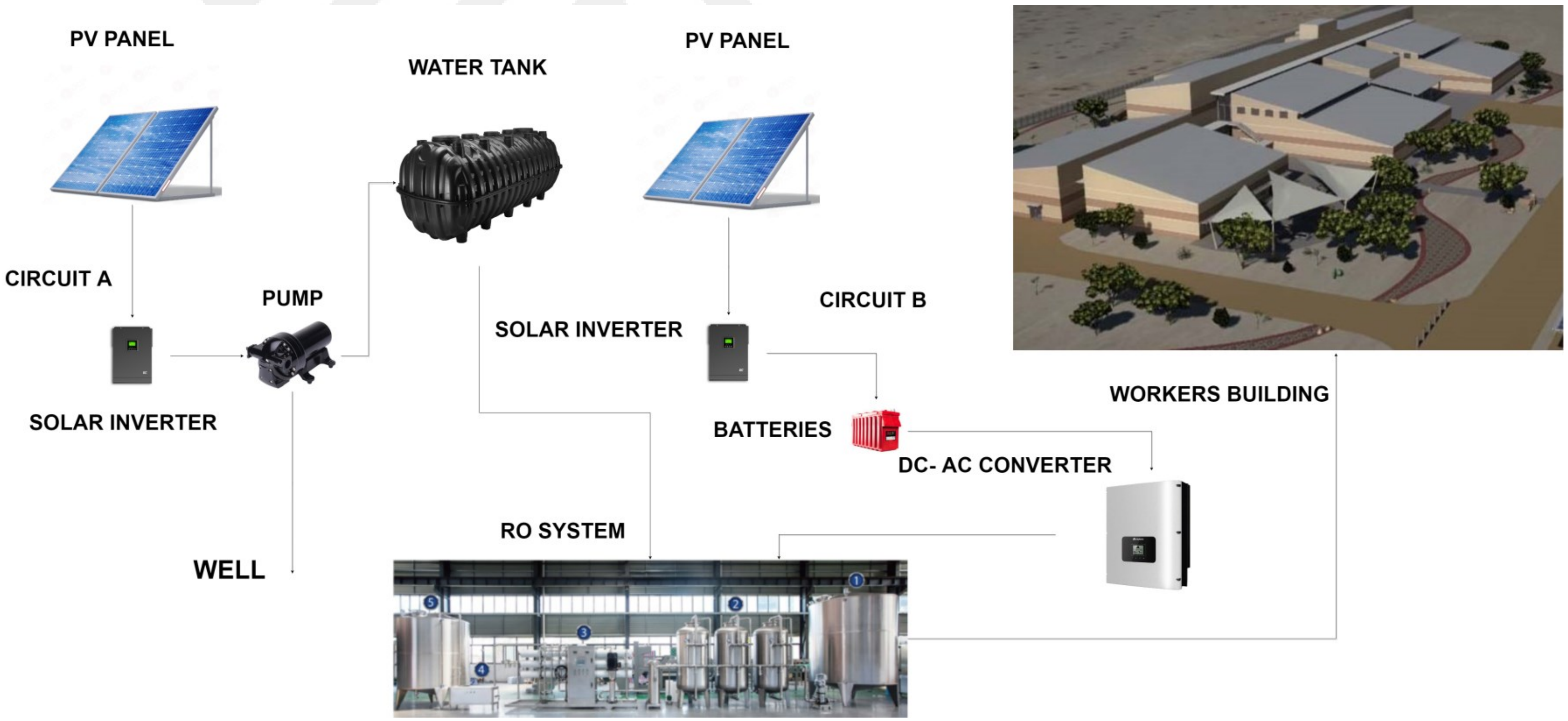


Figure 3. 1. System structure

3.1 System and System Components.

This Section Shows Assumed System Parts and Their Characteristics.

Table 3. 1 system components

COMPONENT	PICTURE	TECHNICAL PROPERTIES	PRICE
PV PANEL (BENQ)		Nominal Power 195 W Panel Efficiency 20.1% Temperature −40° F to +185° F (−40° C to +85° C) Rated Voltage (Vmpp) 24 V	190 $
SHURFLO RV SURFACE PUMP		Power max130 w Nom voltage 12 v Head max 42 m Eff max 34 %	500 $
PIPE		2 inches	500 $ included in the hydraulic circuit and tanks

BATTERIES (ROLLS 12 CS 11P)		Voltage 12 v Capacity 357 ah 20 hrs Weight dry 100KG Weight wet 123KG	1260 $ for each battery
SOLAR INVERTER		Battery voltage 48V maximum charging current 140A Maximum PV power 4000W Efficiency of the inverter 90% - 93%	1000 $
DC-AC CONVERTER		Operating voltage range160 V - 950 V Power 20kw Weight (with mounting plate) 25 kg	1000 $ including the controlling circuit
WATER TANK		Volume 15 m^3 Material Plastic	500 $ included in the hydraulic circuit

Figure 3. 2. RO system

Power: 20 kw **Recovery**: 60 % – 70 %

Capacity: RO 10000L/H **Voltage:** 220 V 50 H

3.2 Climatic Data in Iraq.

Due to the region's easy access to low-cost fossil fuels, the Arabian Peninsula has been slow to adopt solar power. At 1776 MJ/m^2 or 492,333 kilowatt-hours, Iraq's solar power generation capacity is the highest in the world

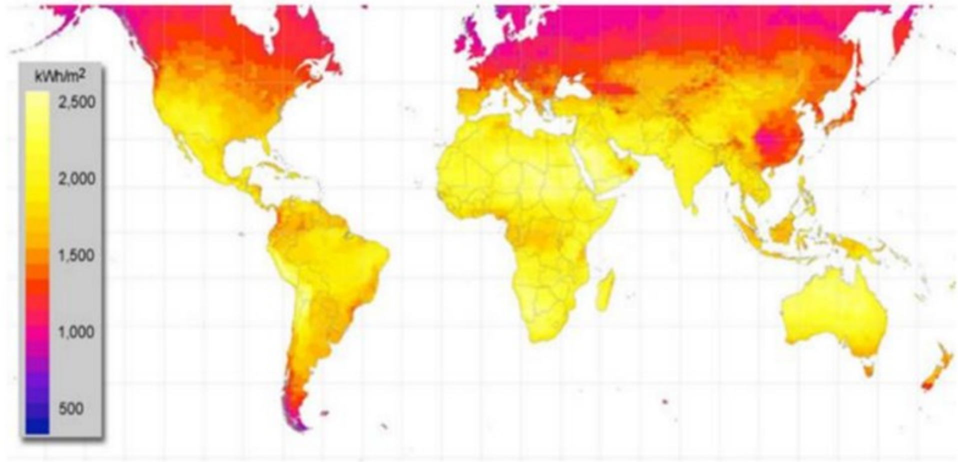


Figure 3. 3. Iraq location at global irradiance (1850-2300 kwh/m2) (107)

(kWh) (106). As a result, Iraq might replace its reliance on fossil fuels with solar electricity and emerge as a major player in the global energy market. Increasing worldwide energy demand can be attributed to the development and progress of societies as well as the need for comfortable living circumstances and transportation(107).

Photovoltaic (PV) technologies that make use of solar cells have made solar energy a practical option for generating electricity. It can be used in numerous contexts, such as solar farms, grid-connected PV systems, self-consumption at home, power transmission, satellites, airplanes, and even electric cars. When compared to the use of fossil fuels, solar energy makes the most sense in Iraq(108).

Concentrated solar heating or photovoltaic cells are used to convert solar energy into electricity. Crystalline solar cells are the preferred technology for photovoltaic (PV) systems in Iraq. Thin-film solar panels are found widespread use in niche markets. Electricity can be generated using solar photovoltaic technology in remote desert places, and fossil fuel emissions can be lowered by using hybrid solar power plants with diesel engines(109).

3.2.1 Solar Density in Basra.

Throughout its whole country, from the northern to the southern sections, Iraq enjoys a vast solar resource. Iraq, which is located in the Middle East on the northeastern edge of the Arabian Peninsula, is close to a very solar-rich region. From May through September, the country has its hottest weather, with average highs of 56 degrees Celsius. The coastal area of Basra province, located at (Latitude 30.51 N Longitude 47.788 E Altitude 8m), stands out for its increased humidity levels due to its location in an otherwise arid region of Iraq(110).

Table 3. 2. monthly meteo of Basra (111)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Horizontal global	87.5	99.2	147.3	165.5	193.0	204.3	204.4	191.3	170.0	135.3	98.8	87.6	1784.2	KWh/m^2
Horizontal diffuse	48.0	62.7	80.2	93.2	105.5	103.5	103.5	99.1	72.9	68.8	49.3	43.7	930.4	KWh/m^2
Extraterrestrial	181.8	202.3	271.4	306.6	344.5	343.2	349.6	328.2	280.0	240.5	187.0	169.2	3204.5	KWh/m^2
Clearness Index	0.481	0.490	0.543	0.540	0.560	0.595	0.585	0.583	0.607	0.562	0.528	0.518	0.557	ratio
Ambient Temper.	10.3	14.1	20.4	26.3	33.8	36.8	38.6	37.8	32.4	27.4	18.0	12.3	25.7	°C
Wind Velocity	1.2	1.9	2.1	2.3	2.6	3.8	3.4	2.8	2.3	1.4	1.4	1.3	2.2	m/s

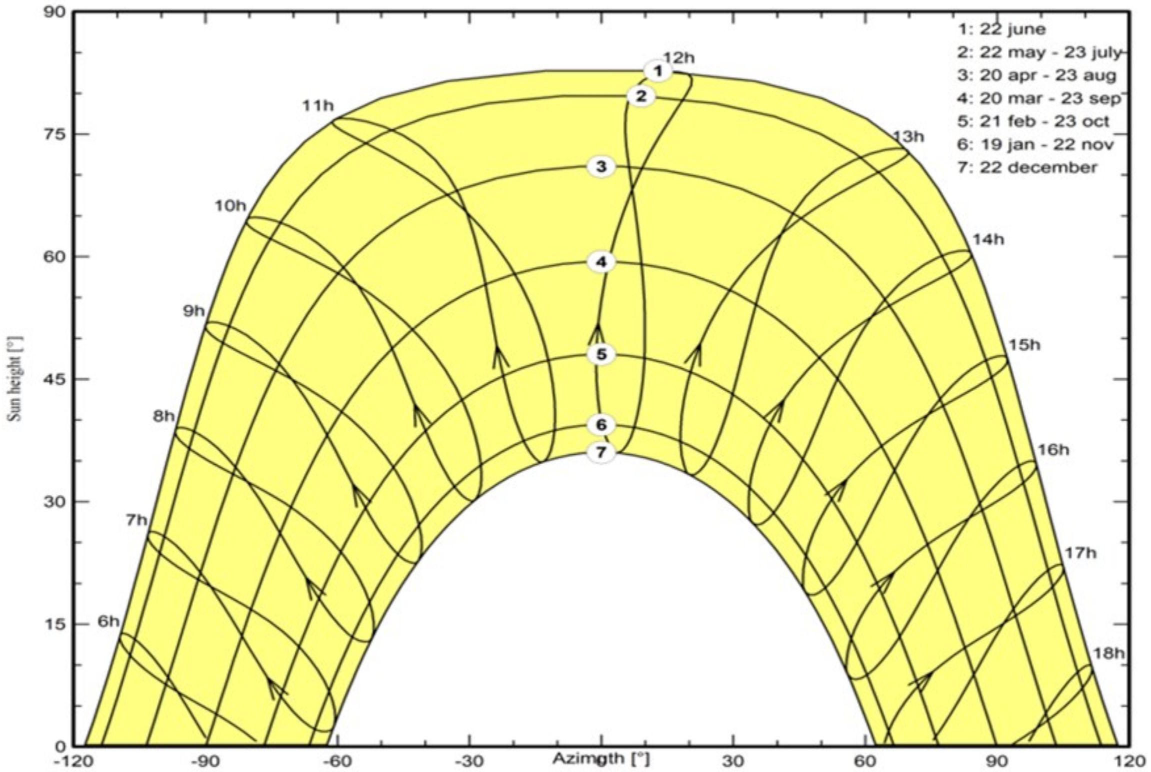


Figure 3. 4. Solar paths of Basra

3.2.2 Ground Water in Basra.

The research area covers an average of 2,874.2 km^2 and is located in the Basra governorate in the Zubair-Safwan area between the longitudes of (47 55'0"-47 30'0") Easting and the latitudes of (30 27'0"-30 03'0" Northing. Fig 3.5 Shallow valleys in the research area serve as regional drainage networks. These valleys run parallel to one another and are found primarily in the study area's southern and southwestern regions. When it rains, the water collects in the valleys and helps replenish the groundwater table (112).

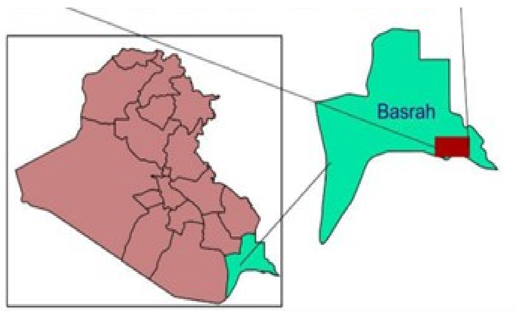


Figure 3. 5. Study area (112)

The Dibdibba formation, which is comprised of sandy gravel soil, is the most prominent geological feature in the region. The Jabal Sanam peak, sand dunes, and shallow wadis are only some of the geomorphological characteristics that can be seen in the Dibdibba plain(113).

As can be seen in Figure3.6 the elevation of the study region varies from 5 to 158 meters above sea level Most of the ground is level, with a gentle decline from the southwest to the northeast. The highest point is at Jabal Sanam(114). The Dibdibba Formation is widely acknowledged as the major aquifer in the research region. A hard clay layer about 2-4 meters in thickness separates the upper unconfined section from the deeper semi-confined to restricted aquifer.

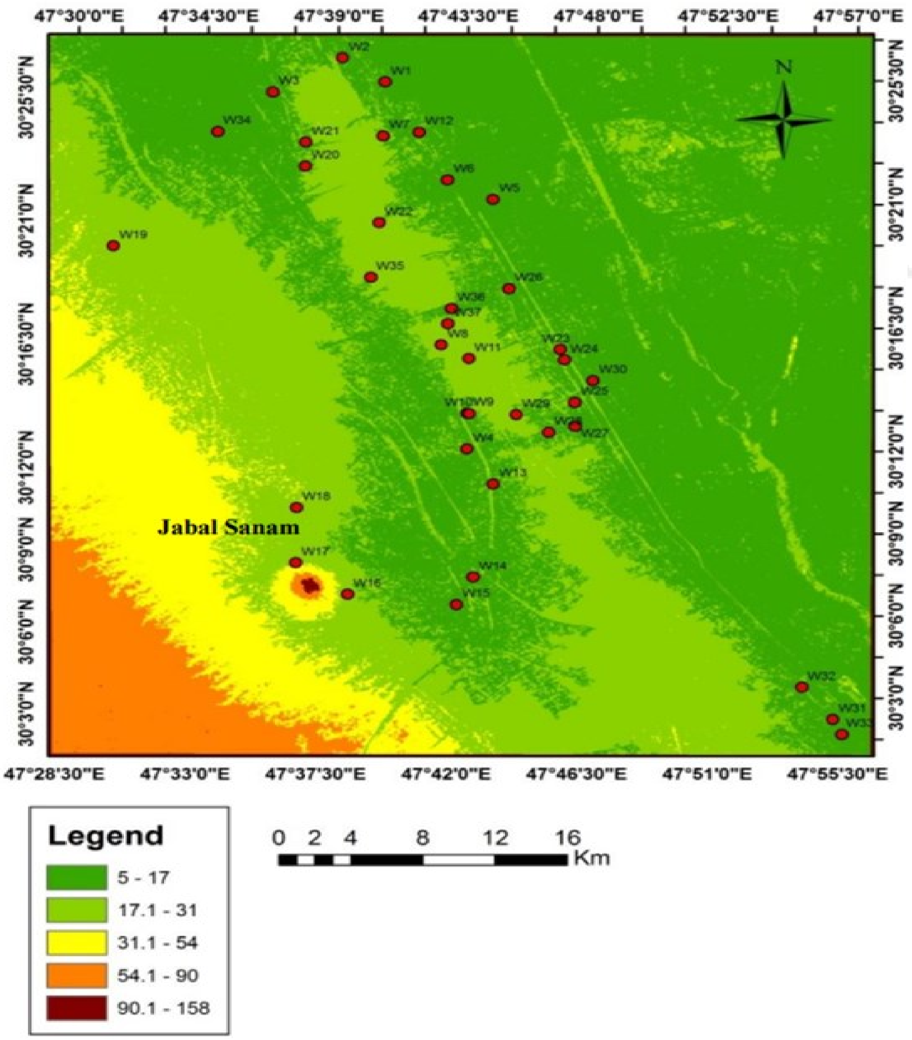


Figure 3. 6. The digital elevation model (114)

Basra's Dibdiba aquifer, which contains water, is often accessible at depths greater than 10 meters. However, the salinity of the water increases in direct proportion to our depth below the earth. Groundwater levels west of Basra are depicted in Figure 3.7.

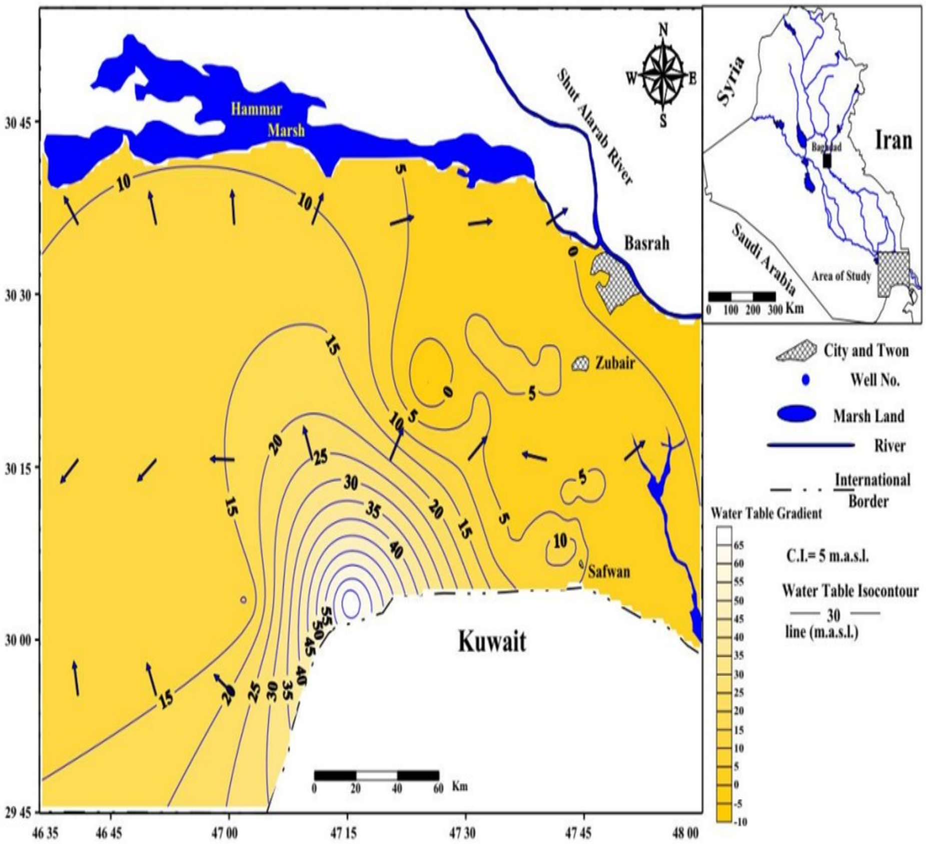


Figure 3. 7. ground water levels in the west of Basra (152)

3.3 Simulation Tools.

In this section, you'll find an introduction to commonly used PV programs like Solarius PV, SAM, PVsyst 6.8.6, PVWatts, and PVGIS 5. The following software packages are included in the hybrid optimization model for electric renewables: PV*SOL premium; RETScreen Expert; BlueSol 4; HelioScope; PolySun; Solar Pro 4.6; and PV F-Chart (PVGIS 5). Monthly and yearly electricity production can be estimated for PV systems with crystalline silicon (c-Si), copper indium diselenide (CdTe), or copper indium sulfide (CIS) solar modules with the help of PVGIS, a free online (115). The PVGIS-CMSAF, PVGIS-ERA5, PVGIS-surface solar radiation dataset-heliostat (SARAH), and PVGIS-COSMO datasets are also included(116). SolarGIS is a web-based simulation application that improves evaluation reliability by providing performance estimates for PV systems. iMaps, ClimData, pvPlanner, and pvSpot are the four programs that make up this suite(117).

Three models "Temperature," "Solar Irradiance," and "PV power" make up the technique. In the updated Global Solar Atlas, Serbia is included (118). The Perez model is used to calculate POA from meteorological models of air temperature. PVWatts, The PV system performance model incorporates aggregated sun and weather data, an equivalent circuit model with just one diode, a five-parameter model, and the Sandia Inverter Model (119).

PVWatts is a web-based simulation application for modeling and operating forecasts of PV systems connected to the grid(120). Using the NREL International weather station's hourly data, the NSRDB's TMY database, and the Perez algorithm, it determines the amount of radiation entering a building from the sun, the sky, and the ground. RETScreen is a program that helps with environmental impact assessment, financial investment appraisal, and energy appraisal. Using data gathered from ground-based weather stations and NASA's satellite meteorological assets, it is possible to predict the weather(121). A meteorological database, a project database, a cost database, and a database of RES components are all incorporated(122).

BlueSol is a program that can be used for PV analysis, optimization, and design. It features a huge library of solar modules and inverters and can model the behavior of PV systems using data from the NASA-SSE or PVGIS databases for solar radiation (123). With inputs including orientation, components, characteristics, inverter model, battery pack, etc., PVsyst is a software for analyzing and designing PV systems to run hypothetical scenarios and generate comprehensive economic evaluations (123). It can also figure out the monthly effects of interrow shade and soiling elements. Meteonorm 7.2's hourly meteorological data is synthesized in PVsyst 6.8.6's model of PV systems, which also analyzes performance, offers solar and weather data, and more(124). HelioScope is a program for analyzing and planning photovoltaic (PV) installations.

The impacts of shading and temperature, the effectiveness of individual system components, wiring, module mismatches, soiling, and aging are all analyzed(125). It shows the PV system's hourly energy output, as well as the weather, PR, and other information(126). With PV*SOL premium, you can perform a thorough shading analysis of your PV system in either 2D or 3D. A meteorological dataset is extrapolated from either NASA's database(78) or Meteonorm 7.1.

Hay and Davies's anisotropic sky model is used to estimate radiation at the point of arrival (POA), whereas Hofmann and Seckmeyer's model is used for computations of diffuse radiation(127). When determining the efficiency of a PV array, either a linear or dynamic temperature model is utilized. Solarius PV is a program that evaluates PV systems from a technical, financial, and greenhouse gas (GHG) emission perspective(128). It includes things like hourly energy output, a cost-benefit analysis, and an amortization schedule. It also factors in the effects of shadows and estimates of radiation from the point of zenith (129). Solar Pro is an advanced photovoltaic (PV) tool that includes 3D CAD and provides shadow, I-V curve, power, and financial analysis(130). Hourly DC power generation estimations are made after taking into account I-V curves for solar modules, total solar radiation determined by geolocation and weather data, and other factors(131).

PV F-Chart is software used for planning photovoltaic (PV) systems, energy storage systems, solar concentration systems, and PV tracking systems(132). It does not factor in shade analysis, weather data, or other elements that could affect loss(132). A solar and geothermal system, cogeneration unit, heat pump, or integrated system can all benefit from PolySun's design, analysis, and optimization features (133). It features thorough analyses of performance, shading, and cost, in addition to a comprehensive library of system components. Meteonorm is a database that stores information about the weather and the amount of daylight. The H.G. Beyer model is used to determine the energy output of a PV system, whereas the Perez model is used to determine the amount of radiation received at the POA (134).SAM is an economic and energy assessment tool for renewable energy sources (135).

Utility-connected photovoltaic (PV) systems are analyzed, including c-Si, thin-film, HIT, concentration (CSP), and multi-junction (MSP) systems, along with their performance and economics(136). Various models, including simple-efficiency and PVWatts, can be used to estimate a PV array's output. Isotropic and/or anisotropic sky models are used in the estimates for POA radiation(137). Micro-grid and hybrid RES systems can both be designed with the help of HOMER, a modeling program that offers technical and financial analysis, system optimization, sensitivity analysis, and greenhouse gas (GHG) analysis(138). It pulls in solar data from NREL and NASA and utilizes the HDKR model to calculate POA radiation (139).

3.4 Comparison Between PVsyst and Other Simulation Programs.

A comparison was performed between SAM, PVSyst, and PVLib, with each program being graded on several distinct metrics. Prior research on commercially available software packages was considered, as was the work that would ultimately depend on the selected software package, to settle on a set of evaluation criteria. A set of criteria for evaluation was settled on in light of these considerations(140). The final list was as follows:

3.4.1 Price and The Ability to Purchase.

SAM and PVLib can be obtained for free by downloading them, but to activate SAM, you will need to acquire a registration key. NREL offers these registration keys at no cost and utilizes the registration data only for statistical purposes. Conversely, PVSyst allows users to utilize the software in an evaluation mode for 30 days without charge, during which it operates at its full capacity. To continue enjoying all the features beyond the evaluation period, users must purchase a license. Otherwise, PVSyst will automatically switch to a demo mode with limited capabilities. PVSyst offers two types of licensed modes: Pro30, designed for PV systems up to 30kW, and Premium, a more expensive option that supports PV systems of any size. The prices for licenses can be found on the PVSyst website. Moreover, PVSyst

extends discounts on licenses for educational purposes to academic institutions such as schools and universities, upon request (141).

3.4.2 Functional Platforms.

PVSyst only works on Microsoft-supported versions of Windows, including Vista, 7, 8, and 10. This includes both 32-bit and 64-bit architectures. However, with the help of virtual machines like VirtualBox, PVSyst can be used with various OSes. Windows 7, 8, and 10 (both 32-bit and 64-bit variants) are all supported by SAM. It is also compatible with the 64-bit editions of OS X and Linux. PVLib comes with a MATLAB toolbox and a Python toolbox. PVLib for MATLAB is designed to work exclusively in MATLAB, while PVLib-python is optimized for the Python programming language. Python (2.7, 3.4, or 3.5) and Pandas (0.13.1 or newer) are system requirements for PVLib-python, which is compatible with Windows, Mac OS X, and Linux. MATLAB may run on multiple operating systems, including Windows, Mac OS X, and Linux (142).

3.4.3 Ability to Be Updated.

There have been 10 changes to PVSyst this year, bringing it from version 6.40 to version 6.49. You may see details about what each update includes when it was released, and any problems that were fixed on the PVSyst website. The current version of SAM is 2016, but it has undergone five updates and adjustments so far this year. There is a new version 3.14 out. Release notes on NREL SAM's website detail each update's alterations and corrections (143). Similarly, there have been multiple upgrades to PVLib this year, with 6 releases. On October 6, 2016, version 0.4.1 was made available to the public. You may find all releases on GitHub, along with brief changelog summaries, documentation for each version, and thanks to the project's primary developers(144).

3.4.4 Ease of Use and User-Friendly Interface.

Both Software SAM and PVSyst have intuitive graphical user interfaces (GUIs), making it possible for non-developers to construct and simulate PV systems with relative ease. These graphical user interfaces make it simple to enter data, run simulations, and examine the outcomes in tabular and graphical formats. Users without programming experience may find it difficult to do PV system simulations with PVLib because of its lack of a graphical user interface and reliance on scripts and functions (145).

3.4.5 Choices for Reporting and Analyzing.

The graphical output of simulations can be viewed in predefined or user-defined graphs, both of which are included as part of SAM. Users can also select to export their data for use in further analysis or presentation software(145). Parametric analysis, sensitivity analysis, statistical analysis, multi-level subsystems modeling, Excel integration, P50/P90 analysis, and the ability to exchange variables are only some of the choices available for assessing simulation results in SAM. PVSyst's major analysis option is P50/P90, and it also provides reports summarizing simulation parameters and main results, allowing for visualization in tables or export to external software like Excel. PVLib, on the other hand, lets users see results graphically or export them to other programs, but it doesn't have any built-in analytic features.

3.4.6 Versatility in Modeling.

Although it is a very capable desktop software, PVSyst does not include scripting functionality. The thermal, electrical, and optical models in PVSyst are proprietary, and users are not allowed to make any changes to them. However, with the help of the manufacturers' datasheets, users can add additional devices to the repository(146). In contrast, SAM is a fully-featured desktop app that comes with its scripting language, appropriately dubbed SAM User Language

(SamUL). With this scripting language, users may automate tasks and do sophisticated analytics in SAM. Although new models cannot be added, users can bring in data from other applications like Excel and TRNSYS. Users can additionally define devices not included in the component database by consulting the corresponding datasheets (147)

On the other hand, PVLib offers more flexibility when it comes to modeling. Since it is built using an open-source methodology, anyone can view the PVLib source code as it is being written. Because of its availability, users can easily modify models, databases, and input techniques to suit their own unique research and design needs. Compared to PVSyst and SAM, PVLib's larger customization options provide customers a leg up in the modeling process.

3.4.7 Capability to Simulate Performance and Economic Factors.

Models of the efficiency of photovoltaic systems, solar water heating, wind power, geothermal power, biomass power, and more are all available from SAM. Grid-connected, standalone, water pumping and DC grid are the categories into which PVSyst places their performance models. PVLib currently only provides a performance model for grid-connected systems and does not include any economic models. There is still room for growth in PVLib (148).

3.5 Performance Analysis of Solar Pumping.

In light of the worldwide energy crisis, scientists have focused particularly on solar-powered water pumping devices (SPWPS)as shown in Figure 3.8. Solar panels, which convert sunlight into power, are the most typical installation.

Solar pumping systems are a marvel of sustainable technology, harnessing the sun's abundant energy to power a number of critical components. These systems are made up of complicated equipment that has been precisely engineered to enhance efficiency and successfully collect solar power. A solar pumping system is normally made up of crucial components such as solar panels, solar inverters, a submersible pump, wires, and a water tank.

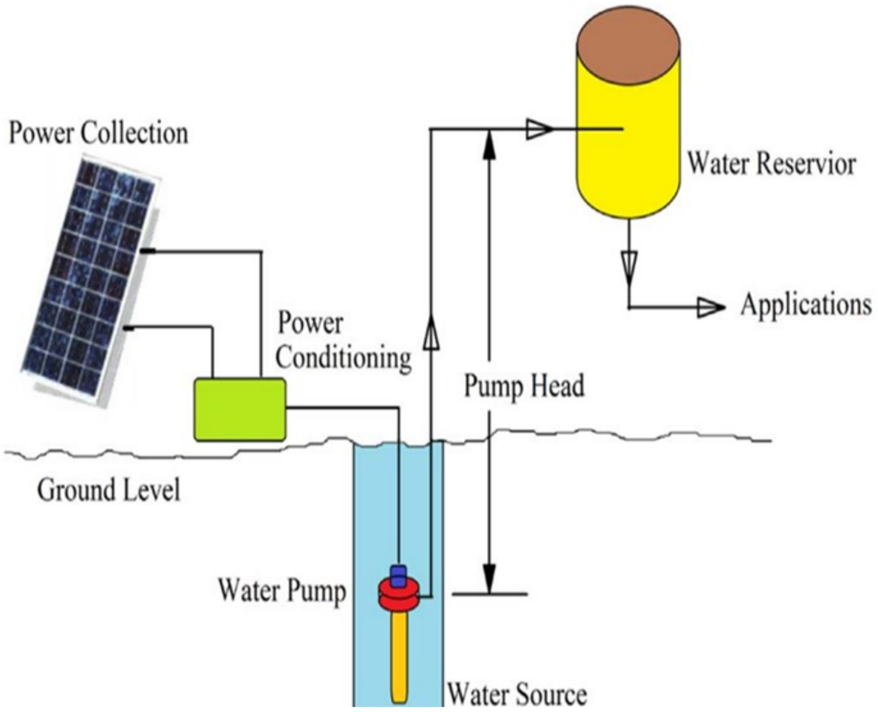


Figure 3. 8. Solar pumping system (149)

In the context of solar irrigation, the procedure is deceptively simple yet complicated. The conversion of solar energy into electrical power by the solar panels is at the heart of the operation. This power is effortlessly transferred through the solar inverter, which serves as a middleman, transferring the generated electricity directly to the submersible pump. This unique feature eliminates the need for extra energy storage units, simplifying the system and increasing overall efficiency.

What's intriguing about this system is how it responds to the changing nature of solar radiation. The flow rate of the submersible pump is not constant, but varies dynamically in real-time to reflect fluctuations in energy obtained from the solar panels. As the amount of solar radiation varies throughout the day, the pump responds with varying flow rates to optimally cater to these shifting energy outputs.

A vital stage in developing these systems is the meticulous selection of each component - the pump, solar panels, and solar inverters. Engineers and designers carefully evaluate and match these components to the precise water requirements, ensuring that the system is not only functional but also optimum for the everyday demands that it will face. This personalized strategy ensures that the system functions at top performance while fully utilizing solar energy, optimizing its environmental and economic benefits(149).

The configuration of the PV array has a significant impact on the efficiency of solar photovoltaic (PV) water pumping systems.

4. CALCULATIONS AND RESULTS

Calculations technical scenario will be studied over 3 wells with different static levels (10 m, 20 m, 30 m well static level) the affection of changing tilt angle will be tested (15 deg, 30 deg, 45 deg) of the solar panel that connected to the surface pump for each static level and how it will change (system power, unused PV power, number of pumps, energy at pump, pumped water, number of PV modules used, pump efficiency, system efficiency, initial cost, return of investment).

Economically profit well be calculated depending upon a relation between RO Water that will be produced by the system depending upon the recovery rate of the RO used that will be represented by the sold water ratio in PVsyst software by entering the RO water price per cubic meter according to the Iraqi market which is 5 dollars per cubic meter and how much will this system cost for installation, operating, maintenance. For 20 years duration of time.

Before the simulation process, the technicality of each well should be known.

- Specific drawdown = 1 (m/ m^3/h)
- Borehole diameter = 15 cm
- Pipe = DN50 (2 inch) (2 elbows)
- Tank volume = 15 (m^3)
- Water need = 15 m^3 (per day) 5475 m^3 (per year)
- PV module 195 (Wp) 24 (v)
- RO system assumed mean recovery rate = 65%
- Pump = Shurflo RV Extreme Smart Sensor 5.7 (surface pump) (150 Watt)

ECONOMICALLY prices will be in dollars assumed as

- Hydraulic circuit: 500 $
- Controllers: 1000 $
- Engineering: 2000 $
- Economic analysis: 1000 $
- Module installation cost: 25 $

- Module price: 190 $
- Pump price: 500 $
- Inverter installation cost: 25 $
- Transport: 1000 $
- Accessories: 500 $
- Wiring: 500 $
- Setting: 500 $
- Well drilling cost: 30 $ per m depth.
- Yearly reparation cost: 500$
- yearly cleaning cost: 250 $
- yearly pump replacement cost:150 $ (pump life assumed 3 years)
- yearly inflation percentage:1.5 %
- sold water ratio: 65 %
- RO water price = 5 $ per cubic meter.

Using PVsyst 7.1 software for making simulation process for RO system power needs and consumption separately as a stand-alone system and all components' prices have been added to the economic evaluation part

4.1 10 m Static Level Well Results.

Table 4. 1. 10 m static level well results

Tilt angle(deg)	Pumping system power (wp)	Pumping unused PV energy (kWh)	number of pumps	energy at pump (kWh)	pumped water(m^3)	number of PV modules used in the pumping system	pump efficiency (%)	system efficiency (%)	General initial cost ($)	return on for general investment (%)
15	585	162	3	665	5335	3	27.7	72.8	61765	514.7
30	585	166	3	678	5406	3	27.6	72.8	61765	522.1
45	585	134	3	678	5419	3	27.7	75.2	61765	523.5

4.2 20 m Static Level Well Results.

Table 4. 2. 20 m static level well results

Tilt angle(deg)	Pumping system power (wp)	Pumping unused PV energy (kWh)	number of pumps	energy at pump (kWh)	pumped water(m^3)	number of PV modules used in the pumping system	pump efficiency (%)	system efficiency (%)	General initial cost ($)	return on for general investment (%)
15	975	335	5	988	5357	5	34.2	64.8	63545	490.3
30	780	127	4	956	5298	4	34.2	77.0	62805	496.1
45	975	308	5	990	5421	5	34.6	65.9	63545	496.9

4.3 30 m Static Level Well Results.

Table 4. 3. 30 m static level well results

Tilt angle(deg)	Pumping system power (wp)	Pumping unused PV energy (kWh)	number of pumps	energy at pump (kWh)	pumped water(m^3)	number of PV modules used in the pumping system	pump efficiency (%)	system efficiency (%)	General initial cost	return on for general investment (%)
15	1170	149	7	1342	4951	6	32.9	73.4	65085	426.4
30	1170	172	6	1423	5270	6	33.0	76.5	64585	467.7
45	1170	115	6	1425	5292	6	33.1	79.0	64585	470.0

5. COMPERSION BETWEEN CHARTS SHOWS THE EFFECT OF TILT ANGLE ON EACH WELL

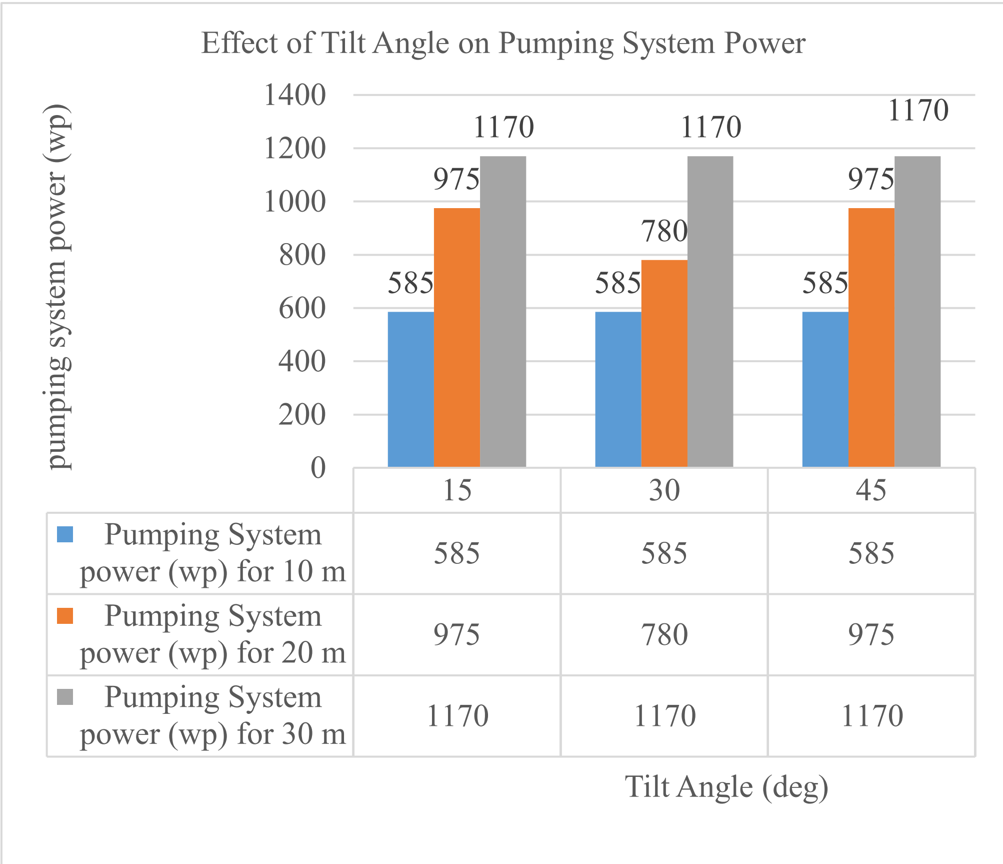


Figure 5. 1. Effect of tilt angle on pumping system power

Figure 5.1. shows that for 10 m and 30 m static level wells pumping system power will not be affected by the variation of tilt angle, but 20 m static level well will decrease at 30 degrees but increase again at 45 degrees tilt angle.

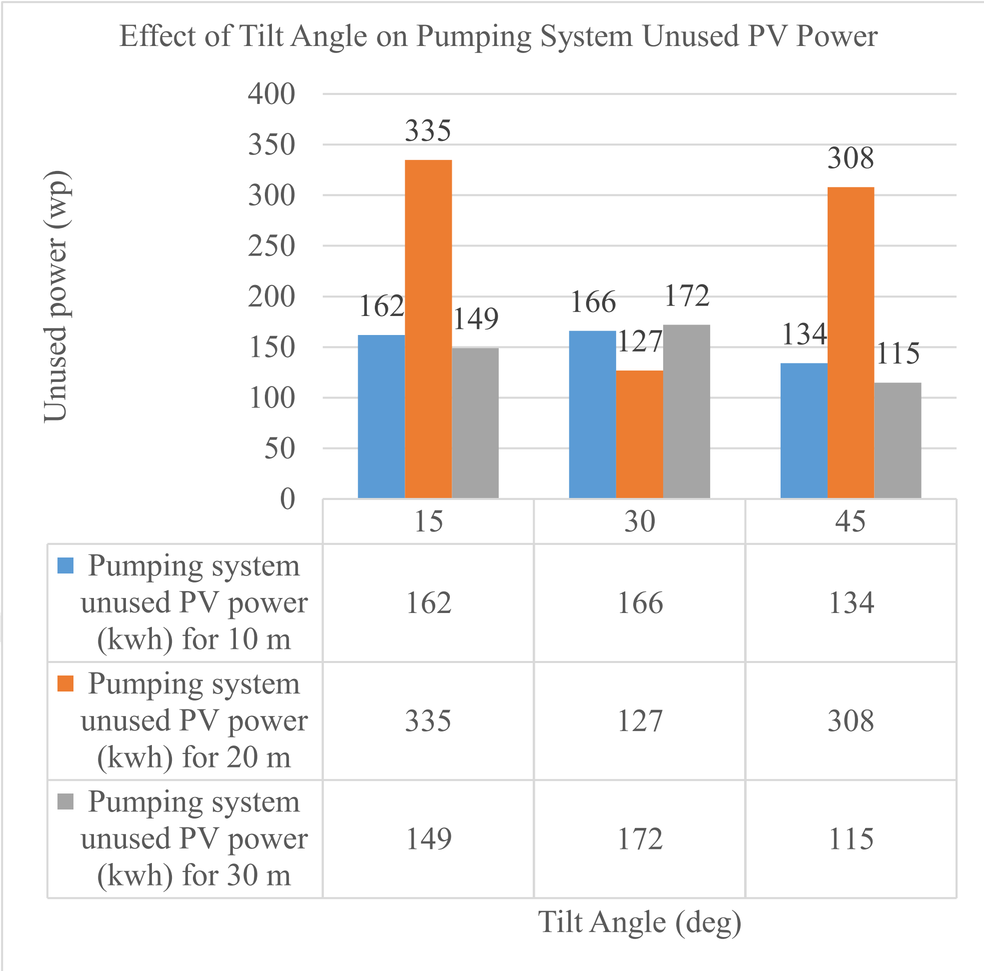


Figure 5. 2. Effect of tilt angle pumping on unused pv power

Figure 5.2. shows that 10 m and 30 m static level wells' unused PV power will increase at 30 degrees and decrease at 45 degrees tilt angle, however, 20 m static level well-unused PV power will decrease at 30 degrees but increase at 45 degrees tilt angle.

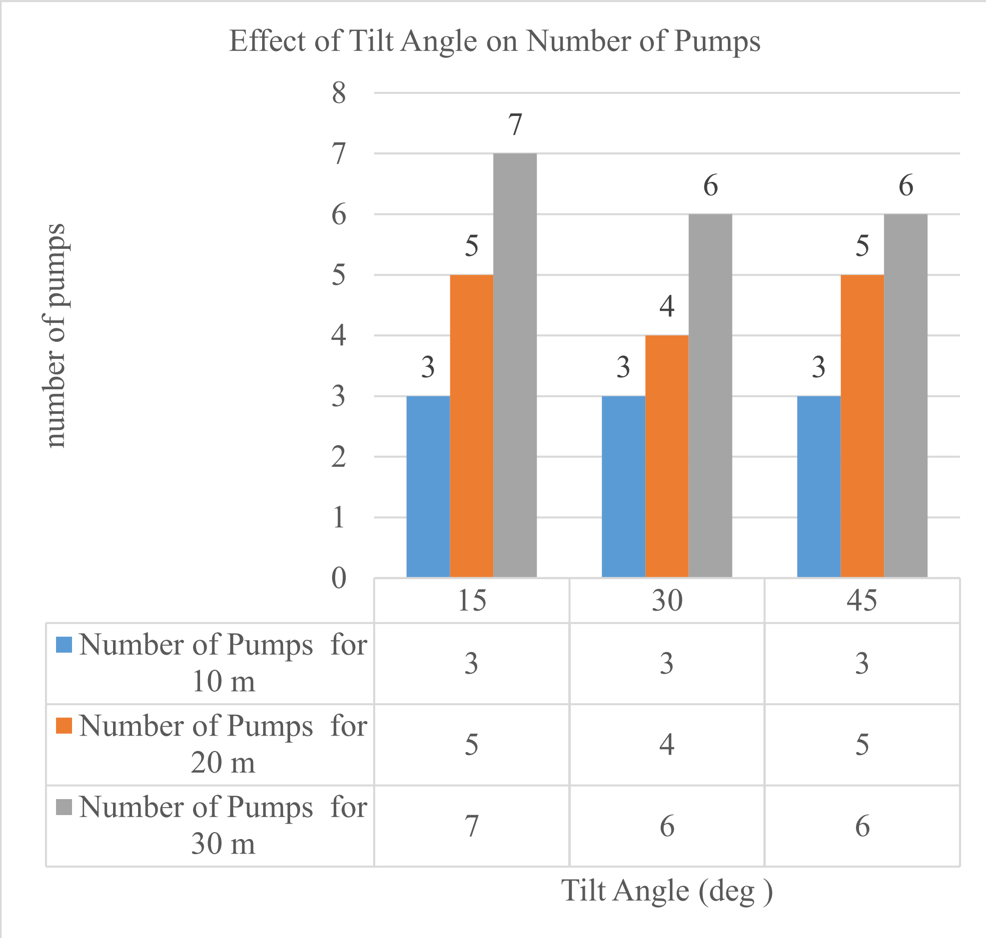


Figure 5. 3. Effect of tilt angle on number of pumps

Figure 5.3. shows that the 10 m static level well number of used pumps will not be affected by increasing tilt angle, but the 20 m static level well number of pumps will decrease at 30 degrees tilt angle and increase again at 45 degrees tilt angle. 30 m static level well number of pumps will decrease with respect to tilt angle increases.

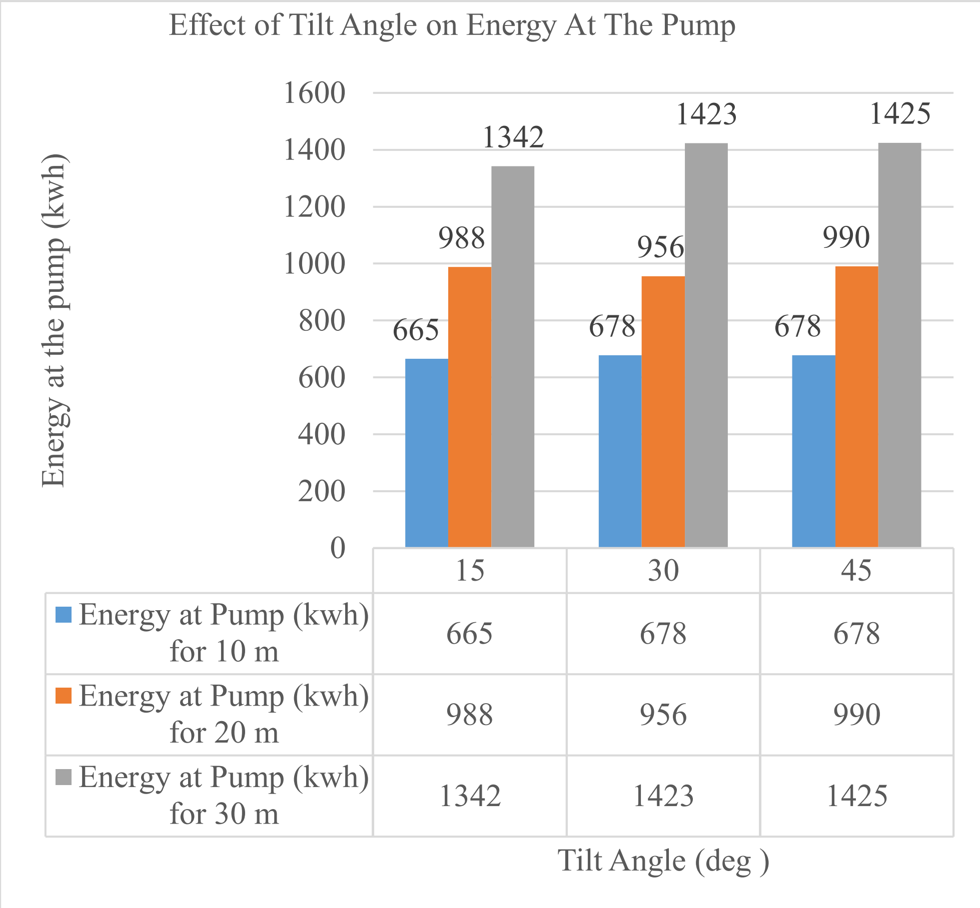


Figure 5. 4. Effect of tilt angle on energy at the pump

Figure 5.4. shows that 10 m static level well energy at the pump increases at 30 degrees tilt angle but remains the same at 45 degrees, but 20 m static level well energy at the pump will fluctuate between decreasing and increasing with respect to tilt angle increasing, however, 30 m static level well energy at the pump will increase with respect to tilt angle increases.

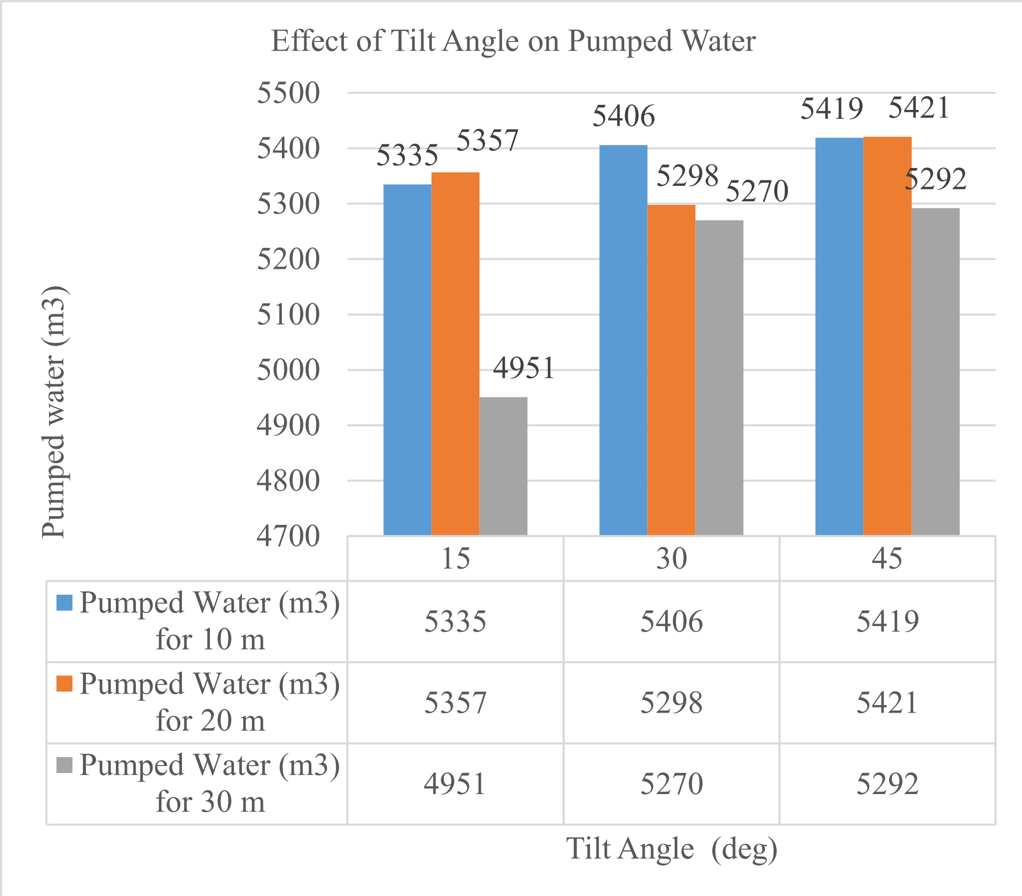


Figure 5. 5. Effect of tilt angle on pumped water

Figure 5.5. shows that pumped water at 10 static levels well increases with respect to tilt angle increasing, but 20 m static level well pumped water will fluctuate between decreasing and increasing with respect to tilt angle increases. Pumped water at 30 m static level well will increase with respect to tilt angle increasing.

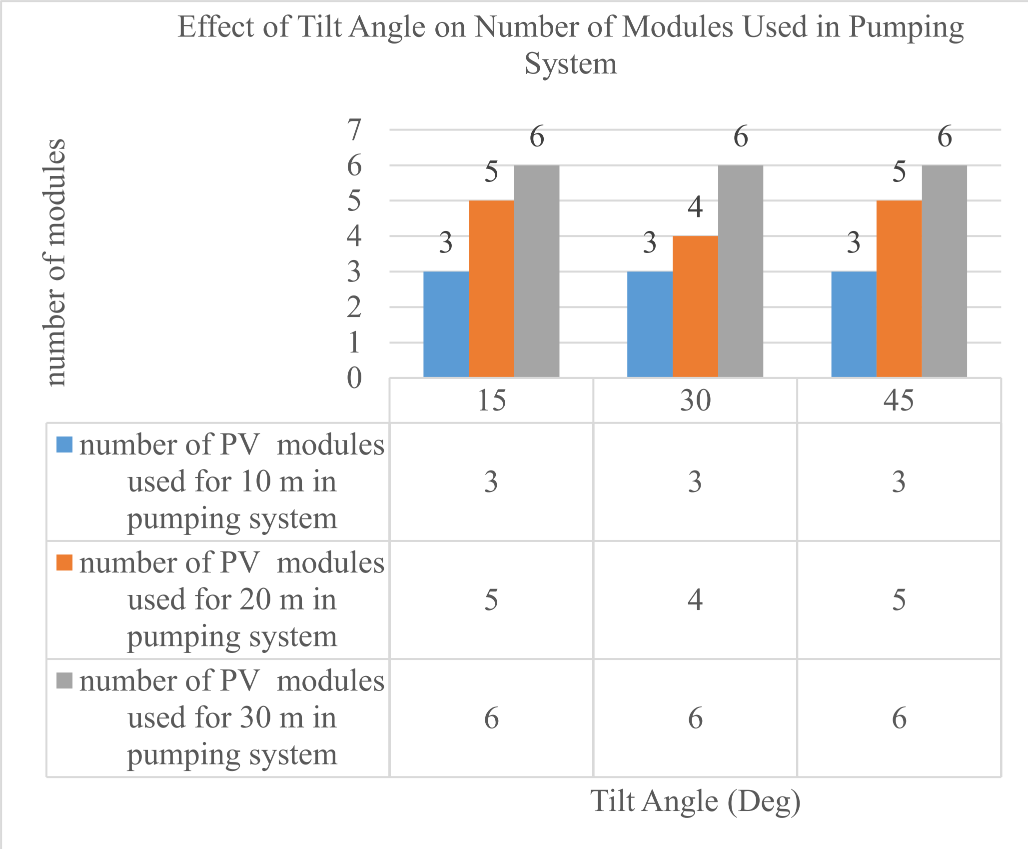


Figure 5. 6. Effect of tilt angle on number of modules used.

Figure 5.6. shows that the 10 m and 30 static level wells number of modules used won't be affected by increasing tilt angle, but the 20 m static level well number of modules used will fluctuate between decreasing and increasing with respect to tilt angle.

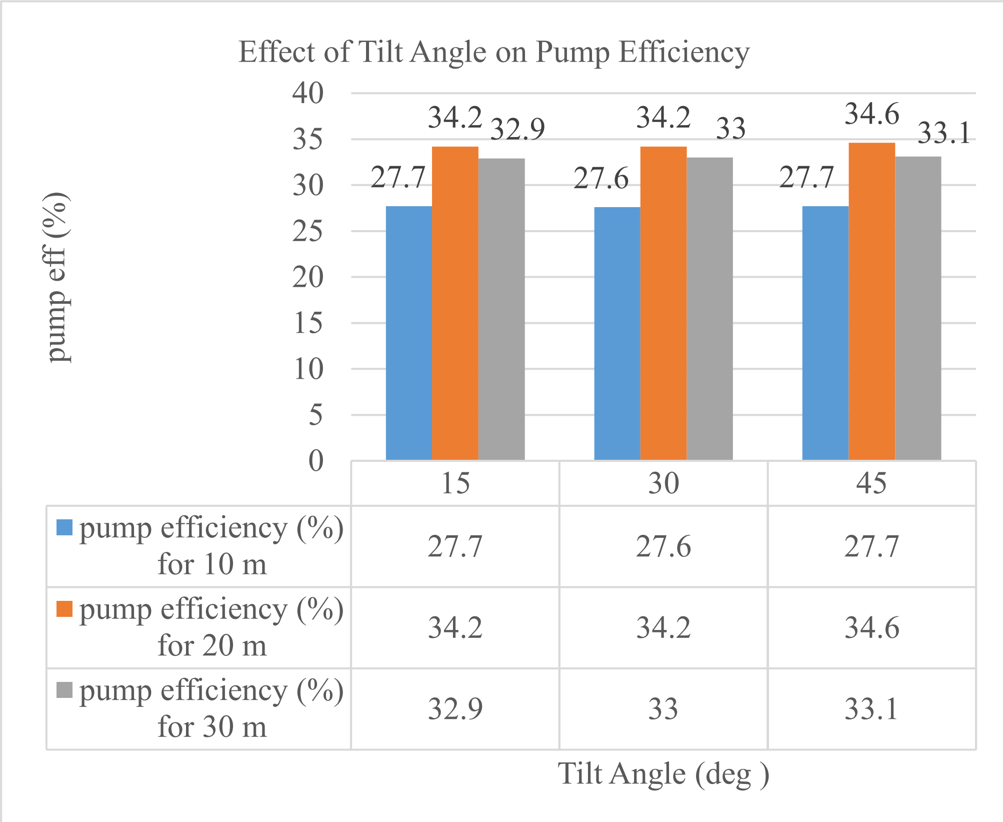


Figure 5. 7. Effect of tilt angle on pump efficiency

Figure 5.7. shows that pump efficiency for all wells with different static levels almost remains the same with respect to the tilt angle increasing.

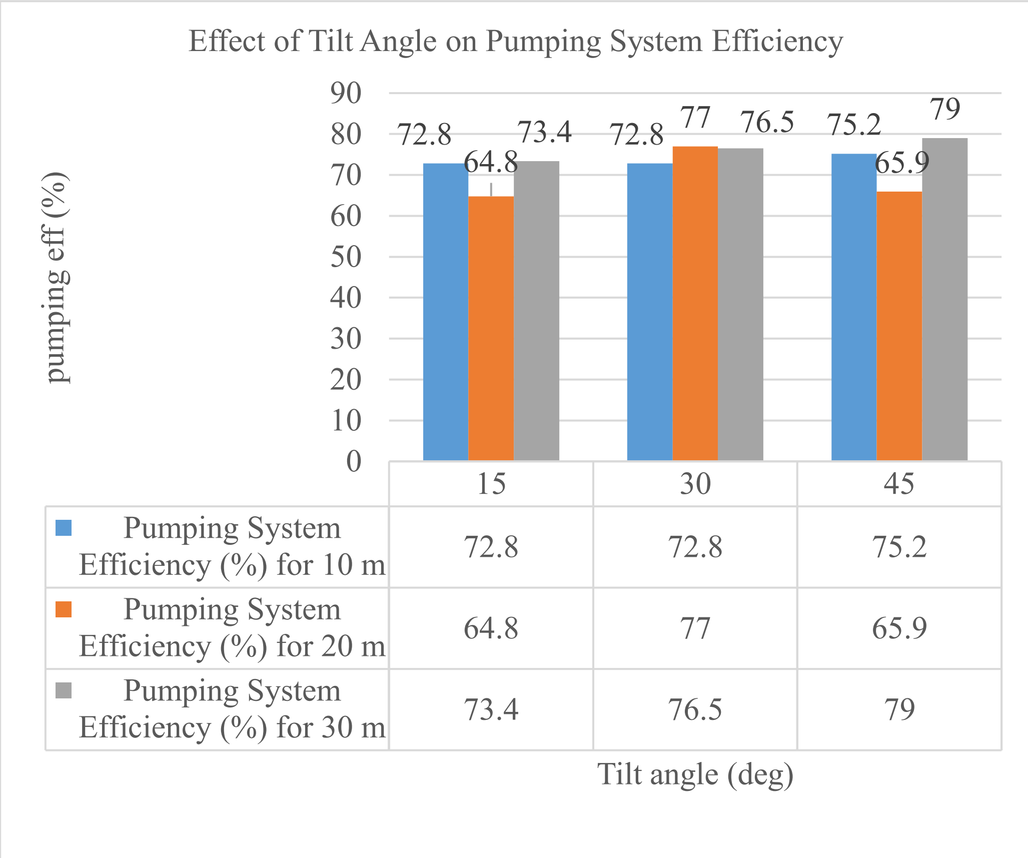


Figure 5. 8. Effect of tilt angle on system efficiency

Figure 5.8. Shows that system efficiency for a 10 m static level well remains the same at 15 degrees and 30 degrees but increases at 45 degrees tilt angle, however, 20 m static level well system efficiency will fluctuate between increasing and decreasing with respect to tilt angle increases. System efficiency for the 30 m static level well will increase with respect to the tilt angle increasing.

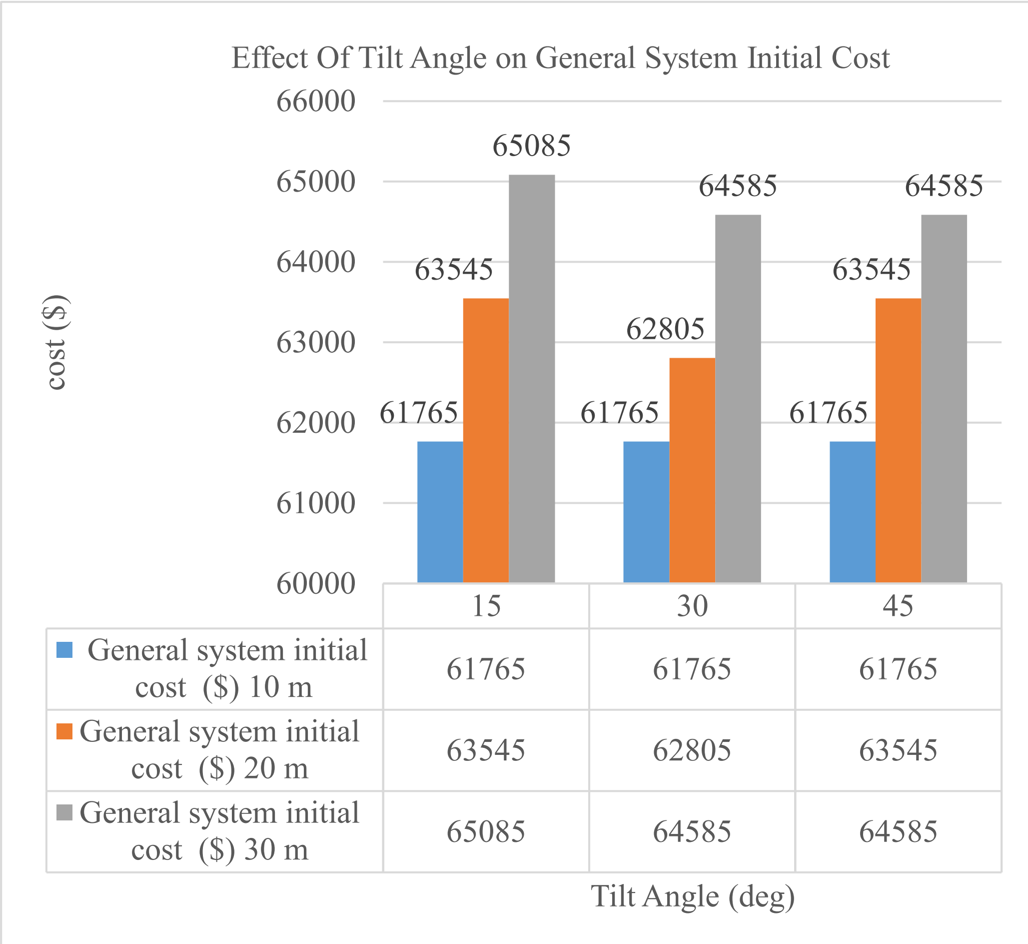


Figure 5. 9. Effect of tilt angle on system initial cost

Figure 5.9. shows that the 10 m static level well initial cost will not be affected by the tilt angle increasing, however, the 20 m static level well will fluctuate between decreasing and increasing with respect to the tilt angle increasing, but the 30 m static level well initial cost will decrease at 30 degrees and remain the same at 45 degrees of tilt angle.

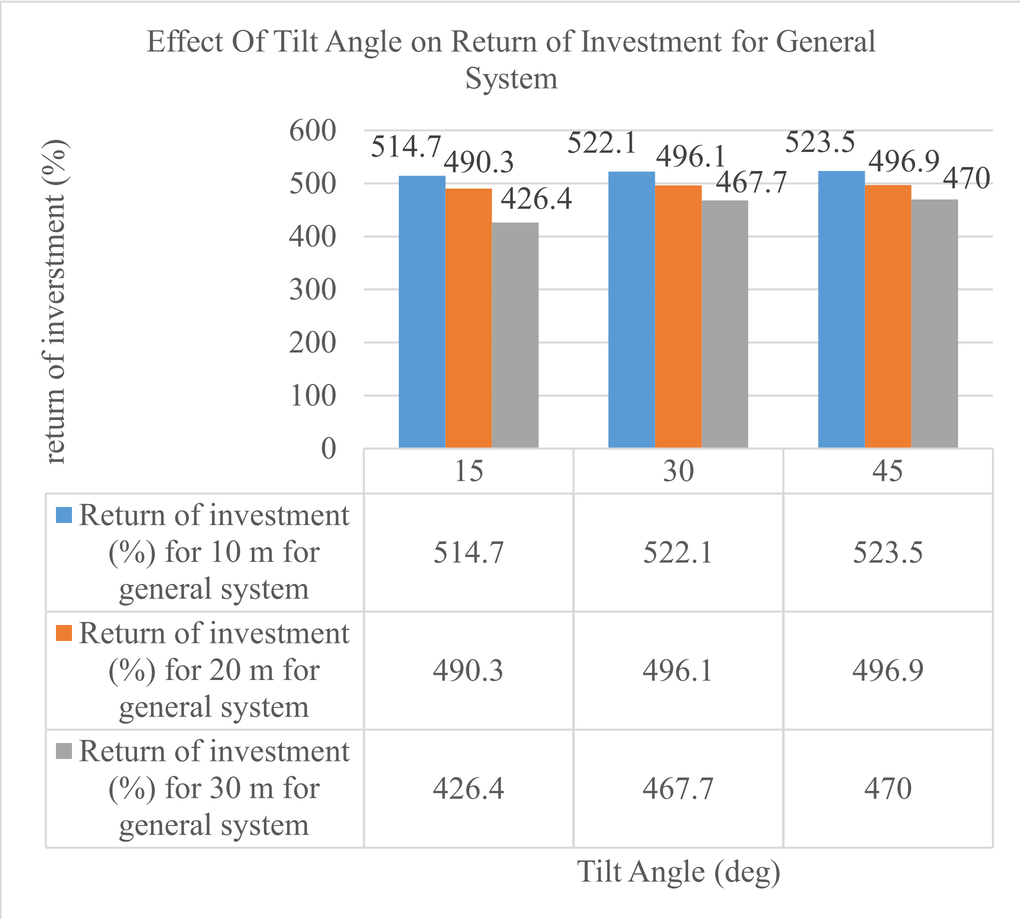


Figure 5. 10. Effect of tilt angle on return of investment

Figure 5.10. presents that all different static level wells (10 m,20 m.30 m) return of investment increases with respect to tilt angle increasing.

6. CONCLUSIONS AND RECOMMENDATIONS

- For 10 m static level well was found that tilt angle won't affect pumping system power, but unused PV energy will fluctuate between increasing and decreasing with respect to angle increasing. Amount of pumps will not be affected, energy at the pump will increase by 30 degrees but stay constant at 45 degrees, pumped water will increase with respect to the tilt angle increasing but the PV panels used will not affect pump efficiency almost remain the same system efficiency same at 15,30 but increase at 45 initial cost remains the same for each case at 10 m. Return on investment will also increase with respect to the tilt angle increasing.
- For a 20 m static level well was investigated a fluctuation in Pumping system power, unused PV energy, amount of pump, pumped water, PV modules used in the pumping system, and initial cost between decreasing and increasing again with respect to tilt angle increasing, However, pump efficiency remains almost the same, But system efficiency fluctuates in an opposite direction with respect to the parameters above. Return on investment will increase at 30 deg of tilt angle but almost the same at 45 deg.
- For 30 m static level with respect to tilt angle increasing Pumping system power, PV modules used in the pumping system, efficiency at the pump will remain the same. number of pumps, the initial cost will decrease with respect to the tilt angle increasing. energy at the pump, pumped water, system efficiency, and return on investment will increase with respect to the tilt angle increasing. unused PV energy will fluctuate between increasing and decreasing with respect to the tilt angle increasing.

- As a general conclusion, the most important parameter affecting the initial cost is the static level that increases the depth as a result that increases the amount of equipment used. Pumping system power is related to the number of pumps and PV panels that are system trying to change their amounts to keep stable ranges of pump and system efficiency with respect to changes in depths and tilt angle. Pumped water is always increasing by increasing energy at the pump. Unused pv energy is always affected by tilt angle. Return on investment is affected by initial cost much more than the other parameters.

- As a Recommendation of this study because of the many advantages of the 45 deg tilt angle will be chosen for those previous 3 different static levels (10, 20, 30) m which is the most efficient most stable most profitable choice, however, the missing pumped water won't affect the pure water that wanted to get keeping the 65% recovery percentage of the RO system.

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