Research Article

Application of MATLAB for Designing and Simulation of High-Efficiency Center Pivot Irrigation System

Filza Fatima Rizvi[1]*, Waqar khan[2], Syed Mohsin Raza Kazmi[3] and Muhammad Umer[4]

[1]Climate, Energy and Water Research Institute, PARC Islamabad, 44000 Pakistan; [2]PMAS Arid Agriculture University, Rawalpindi, 46000 Pakistan; [3]Bahria University, Islamabad, Pakistan; [4]Nust institute of civil engineering, National University of Science and technology, Islamabad 44000 Pakistan.

Abstract | Almost 5000 Glaciers of Pakistan are retreating. They are retreating faster than any other part of the World. Water availability per capita in Pakistan is dropping very alarmingly. Against a dismal supply of 191 million-acre feet, the demand for water is projected to escalate to 274 MAF by 2025, culminating into a deficit of 83 MAF. Pakistan has the world's fourth-highest rate of water use and is already the third most water-stressed country in the world. Being an Agricultural country, more than 90 percent of Pakistan's water resources are used by the agriculture sector. It's a need for time to manage water resources and conserve water. High-efficiency irrigation systems are the most efficient way of water supply to agriculture which can provide better yield with minimum loss of water supply. The current study consists of a design simulation of a High-efficiency center pivot irrigation system on MATLAB. It is the most widely used software for simulation and design purpose which gives a more appropriate, simple and effective representation of results and User-friendly software for linear modeling. The simulation showed 99 % accurate results as the actual readings, e.g. the actual flow rate calculated at the field was 274 GPM while the designed value was 276.76 GPM. The designed total dynamic head was 110.34 feet, while the actual in the field was 108 feet. Through linear modeling, we can get our desired results very quickly and easily by adjusting our input parameters. Such a modeling approach provides a good understanding for engineers to design such water conservation technologies.

Received | September 18, 2019; **Accepted** | March 08, 2020; **Published** | June 22, 2020
***Correspondence** | Filza Fatima Rizvi, Climate, Energy and Water Research Institute, PARC Islamabad, 44000 Pakistan; **Email:** filza.fatima1175@gmail.com
Citation | Rizvi, F.F., W. Khan, S.M.R. Kazmi and M. Umer. 2020. Application of MATLAB for designing and simulation of high-efficiency center pivot irrigation system. *Pakistan Journal of Agricultural Research,* 33(2): 362-370.
DOI | http://dx.doi.org/10.17582/journal.pjar/2020/33.2.362.370
Keywords | Water scarcity, Water conservation technologies, Water center pivot system, MATLAB

Introduction

Pakistan is one of the world's most arid countries, with an average annual rainfall of 240 mm (Farooq et al., 2007). The balance between population and available water already makes Pakistan one of the most water-scarce countries in the world. With the current rate of population growth, it is feared that it will soon enter a condition of severe water scarcity (Briscoe et al., 2005). Population and economy are heavily dependent on an annual influx into the IBIS. The Western Himalayan glaciers may also retreat during the next 50 years, which would result in a decrease of flows (IPCC, 2007c). This would have serious implications for the Himalayan regions' economy, environment and society.

Pakistan is expected to be facing severe water scarcity by 2025. The agricultural sector is the largest user of water, with 93% of total water withdrawals. Around

4% of the total water withdrawals are used for domestic purposes and the rest is used for industrial and other uses. Floodwater, which is not withdrawn for agriculture and domestic uses, is available for delta ecosystems for managing the environment. Temporal variability in the Indus river flows is extremely high as the annual highest flows are almost double the lowest flows an indicator of floods and droughts as a common phenomenon. Although drought is a function of the failure of precipitation due to arid climate reduced river flows also result in a situation of drought for irrigated agriculture. The climatic and hydrologic variability even before climate change is a serious concern in managing the water resources and it may worsen with the expected climate change (Ahmad et al., 2007).

Major crops grown are wheat, rice, cotton, maize and sugarcane which together make about 63 percent of the total cropped area (Agricultural Statistics, 2016-2017). Production of three important crops rice, cotton and sugarcane as well as 90 percent of wheat and most of the maize is virtually confined to irrigated areas. The climate of the country is favorable for two crop seasons under irrigated farming during the year. Wheat is a leading food grain for human consumption, while its straw is used as a source of cheap roughage for livestock feed. There is a wide variation in the cropping intensity of the Rabi and Kharif seasons. The crisis of water shortage for irrigation can only be overcome by proper water management practices efficient use of available irrigation water, evaluation of water requirement of various crops, knowledge of modern techniques of crop and water management.

High-Efficiency Center-pivot irrigation (sometimes called central pivot irrigation), also called circle irrigation, is a method of crop irrigation in which equipment rotates around a pivot and crops are watered with sprinklers. Center-pivot irrigation was invented in 1948 by farmer Frank Zybach, (Javaid, 2011). It was recognized as a method to improve water distribution to fields, High-Efficiency Central pivot irrigation system (HECPIS) is the second most efficient systems among pressurized irrigation systems. HECPIS is a form of overhead sprinkler irrigation consisting of several segments of pipe (usually galvanized steel or aluminum) joined together and supported by trusses, mounted on wheeled towers with sprinklers positioned along its length. The machine moves in a circular pattern and is fed with water from the pivot point at the center of the circle. HECPIS is typically less than 1600 feet (500 meters) in length (circle radius) with the most common size being the standard 1/4-mile (400 m) machine. To achieve uniform application, center pivots require an even emitter flow rate across the radius of the machine. Considering the alarming issue of water scarcity in Pakistan, a center pivot irrigation system HECPIS has been installed at the National Agricultural Research Council and this study highlights the design simulation modeling of HECPIS on MATLAB software. In Pakistan, 50 to 60 % of water is wasted due to inefficient and leaky irrigation systems, wasteful field application methods, and the practice of growing 'thirsty' crops. This is where the opportunity for Pakistan to conserve water lies (World Wildlife Fund-WWF). The design of HECPIS can minimize irrigation water losses up to some extent. Figure 1 is showing the components of valley irrigation system (HECPIS) U.S.A. By adopting HECPIS, following benefits can be achieved;

- 50% water saving
- Precise and uniform application of water,
- High fertilizer use efficiency,
- Increase in cropping intensity
- Lower initial cost than comparable irrigation systems
- Lower maintenance cost
- Even after 15 years, a HECPIS still holds a resale value of 50% of the initial purchase price,
- Pivots deliver higher yields
- HECPIS require less labor, and pumping costs are often lower than other forms of irrigation,
- Easy to manage and Long life
- Crops can easily be rotated as often as necessary.
- HECPIS have the capability to provide up to 95% water efficiency, compared to the 50% efficiency typical in flood or gravity flow irrigation
- Environmentally responsible way to irrigate.

Literature review

Water is a foundation of life and livelihood but water scarcity is become a global alarming issue, which is the main concern of all nations. An increase in population and future climate change are expected to increase water demand and water scarcity world widely and shifts in spatial and temporal availability of water (Foster et al., 2014). Asia is home to 4.5 billion people, which uses 5 % of world water supply. Around 30 % of the Asian population is facing the issue of water scarcity. India faced double-digit GDP growth last year as well as population increase but water resources do not fulfill the demand for water in the country (Satoh et al., 2017). In China, water shortage for agriculture is a great concern of arid and semi-arid zone. Focusing on improving the efficiency of the irrigation system, different irrigation technologies have been adopting e.g. drip, sprinkler, center-pivot irrigation system and film mulch techniques (Li et al., 2019). The availability of water is crucial for the economic and agricultural development of Pakistan, here availability is decreasing year by year (PIPIP Project, 2012).

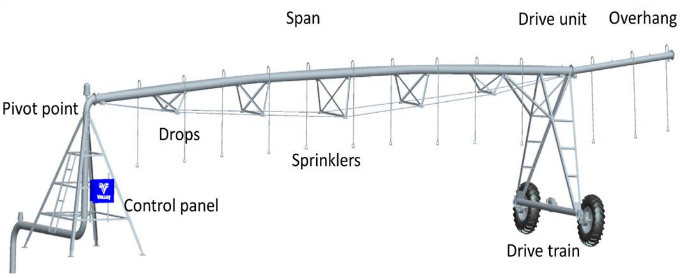

Figure 1: *Valley irrigation-USA.*

Water consumption has been increasing at more than twice the rate of population growth in the last century (FAO, 2012a; UN, 2012). World's 7 billion people are using over 54% of all the accessible freshwater (UNESCO, 2012). The global freshwater used by various sub-sectors1 is a) 70% for irrigation; b) 22% for industry; and c) 8% for domestic use. Water withdrawals are predicted to increase by 50% by 2025 in developing countries, and 18% in the developed countries (UNEP, 2012).

In Pakistan total cultivation area is 29.23 million ha but only 70 % area (21 million ha) is cultivated, with around 12 million ha are under forage and forests. The cultivated area of Pakistan covers 5 major crops on 17.30 million ha (wheat, cotton, rice, maize and sugarcane) other crops cover about 4.70 million ha (GOP, 2015). This makes 41.23 million ha suitable for agriculture and forestry and the area of 24 million ha excluding the urban and rural infrastructure is not suitable for agriculture and forestry within the existing framework, except for rough grazing in certain places. About 8 million ha of land is culturable waste due to lack of water availability and other factors. Average water conveyance efficiency in Pakistan is estimated as 35-40 % from canal head to root zones, with much water losses. Sustainable development of water in this area is one of the major limitations of the expansion of agriculture and forestry. Out of the cultivable area of 29.23 million ha, 18.63 million ha are under irrigation from canals, tube wells, wells, springs, streams, etc. within and outside the Indus Basin. The rest of the 2.78 million ha is under Barani and indigenous water harvesting systems in an average year of precipitation (GOP, 2015).

In the current water scarcity situation of the country, it's important to conserve water for agriculture purposes. Integrated water resource management is a better way to supply water to agriculture in order to minimize the losses. Irrigation systems are the more efficient and modern way of watering to fields that can conserve water. In Pakistan, overall irrigation efficiency is better than other countries e.g. 78 %. Drip irrigation system is the most efficient system mostly apply for orchids; the center pivot system is the second most efficient system for water conservation along with sprinkler irrigation system in the country. Claude, 1975 concluded that uniform distribution by sprinkler system is essential to optimize crop yield; allow minimum sprinkler system capacity, conserve pumping power and make more efficient use of the available irrigation water supplies (Claude et al., 1975). High water distribution uniformity is required to attain a satisfactory level of irrigation efficiency (Dechmi et al., 2003). Different application rates along pivot length, uneven application patterns in different quadrants of field and uneven overlap of sprinklers are the major factors influencing the center pivot distribution uniformity (Gaudy et al., 2007). The application rate does not depend on the system speed but is a function of the operating pressure, nozzle size and the type and sprinkler spacing along with the lateral (Camp et al., 1998). Because the outer sprinklers of center pivot system move faster, they must apply water at about 40% higher rate than the average application rate of the system, thus increasing the probability of exceeding the soil infiltration rate creating run-off and the potential for erosion. Water conservation is the need of the time where water scarcity is prevailing and high-efficiency irrigation is the ultimate measure. Brennan et al. (2006) have reported that farmer loses money by overwatering, due to leaching of nitrogen at high water application. More efficient sprinklers achieve higher economic returns and use less water. Centre pivot irrigation system proved to be very efficient and consists of better irrigation and distribution efficiency as evidence given by research in their research by under various sizes of center sprinkler system.

Many researchers worked and argued in the literature about designing irrigation systems or scheduling for a better supply of water world widely. Drahansky highlighted the study of predicting water requirement of crops in order to support water administration for water supply and distribution in the irrigation system of any region (Drahansky et al., 2016). Considering the issue of water scarcity, a non-linear programming optimization model with integrated soil water balance has been developed by researchers in order to determine the cropping pattern and optimum water allocation in the South West of Iran (Sadati et al., 2014).

Many software has been developed and widely used for designing and simulation of many irrigation systems e.g. SIRMOD, WinSRFR, IrriProb, SISCO, SPRINKMOD, AquaCrop, etc. (Koech et al., 2010). SIRMOD software considers the distribution of infiltrated water, simulated irrigation performance, volume balance and runoff hydrographs. WinSRFR works for analysis, simulation, physical design and operational analysis. IrriProb has the capability to simulate multiple furrows and optimize irrigation system performance on fields. SISCO is used for both the furrow and bay system. AquaCrop is another model which use for simulation, which considers the link of crop yield to water use (González et al., 2018). MATLAB is used mostly for high-efficiency irrigation designing, center pivot irrigation designing. MATLAB has been used by many researchers for irrigation scheduling, modeling and simulation (Koech et al., 2010; Gbegbelegbea et al., 2017). Agriculture atomization is another tool in order to optimize the supply of water on the field, Janani intended to reduce the human intervention in the field and to irrigate the field through image processing on MATLAB software for knowing the condition and type of soil for crop cultivation (Janani et al., 2016). Biswas has applied MATLAB for dynamic modeling of solar power irrigation system, MATLAB simulation has been performed with two systems, electrically operated system and water storage tank, comparison has been made between these two systems with conventional diesel operated pump for irrigation systems (Biswas et al., 2018). Hence, MATLAB can be used efficiently for the simulation modeling of any irrigation system more with better and good results interpolation, this is because MATLAB has given preference for the simulation purpose in current study.

Materials and Methods

SIRMOD main output screen (Figure 1) includes a plot of the distribution of infiltrated water, simulated irrigation performance, volume balance and the runoff hydrograph SIRMOD main output screen (Figure 1) includes a plot of the distribution of infiltrated water, simulated irrigation performance, volume balance and the runoff hydrograph MATLAB is one of the most running engineering software, which is User-friendly, easy and simple. It consists of many build-in functions, toolboxes, many computations for designing, simulation, optimizations, data analysis, solution of ordinary or partial differential equations and for multi-dimensional purposes. In this study, MATLAB was used for the designing of the center pivot system. For design purposes, this study has simulated the model on MATLAB with already installed HECPIS at the National Agriculture Research Center (NARC) Islamabad.

The following parameters were considered for modeling of HECPIS on MATLAB.

- Reference Evapotranspiration (mm)
- The total length of towers (ft)
- Area of center pivot circle (acres)
- Total discharge (GPM)
- HECPIS machine speed (ft/min)
- Irrigation hours
- Discharge requirement for an area under different towers (GPM)
- The internal diameter of the tower (inch)
- The velocity of the center pivot system (ft/s)
- Total fractional losses
- Total dynamic head (psi)
- Pump and motor efficiency
- Horsepower requirement (hp)
- The current requirement for a prime mover or unit motors
- Total voltage requirement (V)

Programming Scripts for the designing parameters is shown in the appendix.

Design guidelines of HECPIS

The contents of these guidelines were intended to provide general design HECPIS. Proper design is the first critical step in providing the customer with a system that will operate satisfactorily for many years. It is the responsibility of the designer to ensure the equipment is applied within the design parameters. Certain field slopes, climatic conditions, crops and management practices may necessitate limiting the application of the equipment. Flowchart is showing the design worksheet of HECPIS (U.S.A).

1. Field Elevation + ______' - ______' from Pivot Point

2. Maximum Field Slope ______% and Ridge (Furrow) Height ______"

3. Soil Textural Classification ______

4.

Type Crop	Gross Consumptive Use In. Per Day	Root Depth
______	______"	______'
______	______"	______'
______	______"	______'

Potential GPM Reduction for Heavy Soils or Low GPM Availability

Available Moisture at Field Capacity in Soil Profile for Plant Use Plus Minimum Recorded Rainfall During Peak Use Days		Peak Consuptive Use Days	Potential* Reductions Inches/Day
______"	÷	______	______"
______"	÷	______	______"
______"	÷	______	______"

Required Inches/Day				GPM/Acre		Irr. Acres		System GPM
______"	÷	.053	=	______	x	______	=	______
______"	÷	.053	=	______	x	______	=	______
______"	÷	.053	=	______	x	______	=	______

5. Maximum Operating Temperature ______ Degrees

6. Altitude Above Sea Level ______ Feet

7. Field Dimension (______' x ______') ÷ 43,560 = ______ (Field Acreage)

8. System Length & Configuration

______' + ______' + ______' + ______' = ______
(Length to Last D.U.) (O.H.) Total System Length (Eff. E. G. Rad.) Eff. Irr. Length

Pivot ... LDU

______ (______) Pivot to Last Drive Unit ______
______ (______) Pivot to End Gun ______ ______ Effective End Gun Coverage
______ (______) Effective System Coverage ______

9. Acres Irr. End Gun Off = $\frac{(3.14)\ (\text{System Length}^2)}{43560}$ X % Field End Gun Off = ______

Acres Irr. End Gun On = $\frac{(3.14)\ (\text{System Length}^2)\ \text{With End Gun On}}{43560}$ X % Field End Gun On = ______

Total Irr. Acres ______

10. System Pressure Requirement

Pipe Size	Length	Percent Length
6"	______ft.	______%
6-5/8"	______ft.	______%
8-5/8"	______ft.	______%
10"	______ft.	______%
TOTAL	ft.	100%

Determine Pressure Loss in an all 6-5/8"(168 mm) System ______ (See Table 1)

OR

See worksheet & pressure profile - Pressure Loss Section — Total Friction Loss = ______

11. Total System HP:
Pumping Level .... ______ft.
Mainline Pressure Loss ______ psi x 2.31 .... ______ft.
System Friction Loss ______ psi x 2.31 .... ______ft.
Spk. Pgk. Press Requirement ______ psi x 2.31 .... ______ft.
Pivot Elevation .... ______ft.
Field Elevation .... ______ft.
Elbows, Valves, Pump Pipe & Misc. Press Losses ______psi x 2.31______ft.
Total Feet Head = ______ft.
Over Design - 10%/15% = ______ft.
Designed Feet Head = ______ft.

Pump Hp = $\frac{\text{(Ft. Head) GPM}}{\text{3960 X Pump Eff.}}$ Hp = $\frac{(\quad)(\quad)}{(\quad)}$

12. Total Hp = Pump Hp ______ + Gen. Hp ______ = ______

13. System Electrical

System Length to LRDU	______	Ft.	______	Total Number of Drive Units
Pivot Voltage	______	VAC		
Machine Speed	______	Std.	______	Hi
Booster pump	______	None	______	2 HP ______5 HP ______7.5 HP
System Amp Draw	______	Amps		
Voltage Drop	______	Volt Drop		
Booster Transformer Package (1 per System)	______	Yes	______	No
Booster Transformer Location @	______	D.U.		
45 Amp Package (1 per System)	______	Yes	______	No
D.U. Fuse Package	______	Pkgs.	(Quanity = #D. U.)	
Corner Fuse Package	______	Yes	______	No
10ga to 8 ga Wire Fuse Package	______	Yes	______	No
Booster Pump Fuse Pkg. (2 HP)	______	Yes	______	No (1 per system)
Spans of 8AWG Wire	______	Spans		

14. Generator size ______ Generator HP ______

Flowchart: *HECIPS design work sheet (United States Department of Agriculture- USDA).*

Results and Discussion

Using the design guideline sheet of HECPIS which was developed by the U.S Department of Agriculture, USDA and MATLAB software peak crop water requirement of Mungbean was calculated. Crop coefficient (Kc) values for Mungbean and Reference Evapotranspiration (ETo) values for Islamabad/Rawalpindi regions were used (Food and Agriculture Organization (FAO) and the International Water Management Institute (IWMI). The peak crop water requirement calculated for mungbean was 7.467 millimeters per day (mm/day) keeping in view irrigation efficiency of 90% for HECPIS. Based on the peak value a total flow rate of 276.76 gallons per minute (GPM) per day came out for total area of 49.90 acres.

Later on, based upon percent timer of HECPIS hours per revolution and millimeter application values were calculated accordingly. Friction losses and flow velocities in the PVC Mainline from tube well to pivot point and from Galvanized Iron (G.I) pivot point to overhang were calculated using Hazen Williams and Darcy-Weisbach equations respectively. Total dynamic head and flow rate yielded pump horsepower and pump prime mover horsepower. Based on the total horsepower requirement total kilowatt (KW), kilo volt-ampere (KVA) and amperes were calculated.

MATLAB gave us a cushion of results in figures as well as graphical trends which usually and most other software do not provide simultaneously. Maximum Peak Crop Water Requirement of Mungbean in mm/day: 7.467. Figure 2 shows the relation between ETo and Kc. In the beginning, there is a direct relationship between ETo and kc until the specific point of the chart and then there can be seen a decreasing trend between ETo and Kc.

- Total Length of Center Pivot System from Pivot point to end in feet: 831.8
- Area of center pivot circle in acres: 49.9
- Gallon per minute (GPM) for 49.9 acres for 24 irrigating hours in Peak: 276.7

Table 1 is showing the Hours per revolution of Center Pivot w.r.t to percent timer. Figure 3 is showing the relationship of percent time setting and hours per revolution of the center pivot system. With increase in percent time setting, there is a decrease in hours per revolutions. Table 2 is showing the Millimeter per revolution w.r.t to Hours per revolution of Center Pivot. Figure 4 is showing the direct relation between hours per revolution and mm per revolution.

Table 1: *Hours per revolution of Center Pivot w.r.t to percent timer.*

% Timer setting	Hour per revolution
100%	5.77
90%	6.41
80%	7.21
70%	8.25
60%	9.62
50%	11.54
40%	14.43
30%	19.24
20%	28.86
10%	57.71

Table 2: *Millimeter per revolution w.r.t to hours per revolution of center pivot.*

Hour per revolution	Millimeter per revolution
5.77	1.60
6.41	1.78
7.21	2.00
8.25	2.29
9.62	2.67
11.54	3.20
14.43	4.00
19.24	5.34
28.86	8.00
57.71	16.02

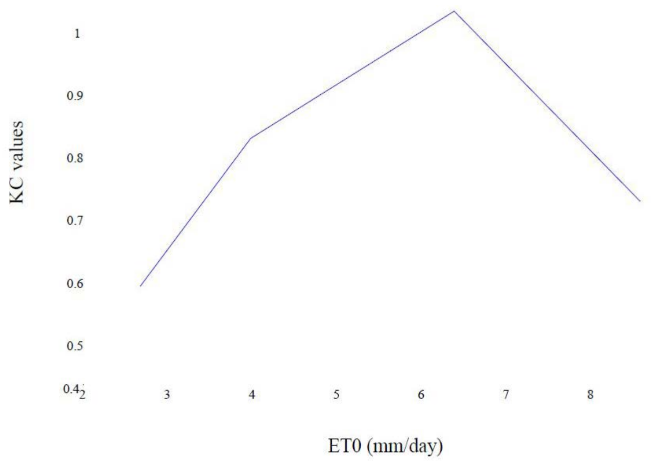

Figure 2: *Chart between ETo and Kc values at different stages.*

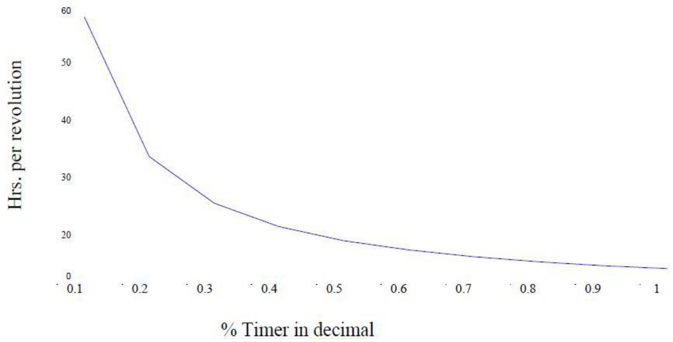

Figure 3: *Chart between percent timer hours per revolution.*

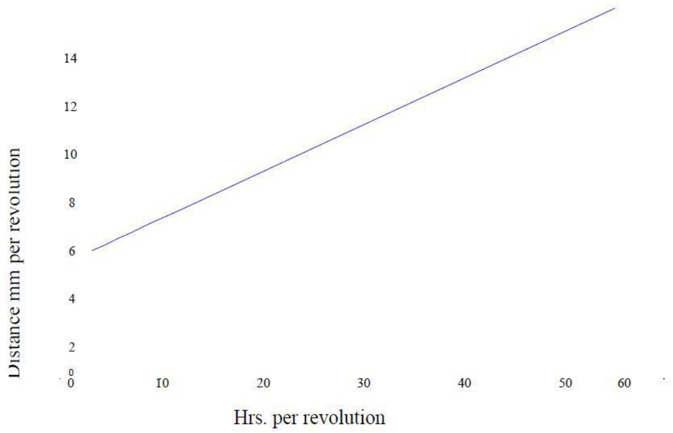

Figure 4: *Chart between hours per revolution and distance mm per revolution.*

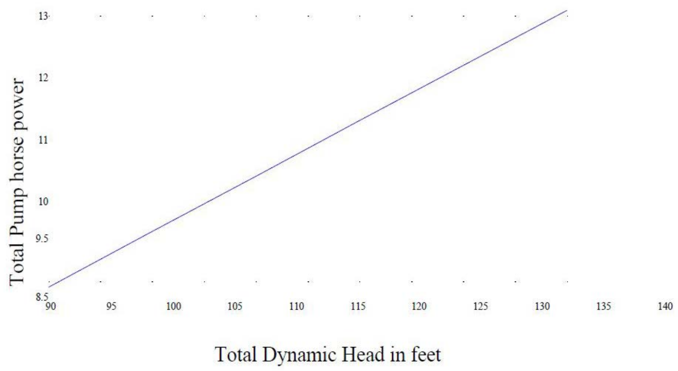

Figure 5: *Chart between total dynamic head and total pump horse power.*

Designed parameters of HECPIS

- Gallon per minute (GPM) required for the area under tower 1: 12.96
- Gallon per minute (GPM) required for the area under tower 2: 38.88
- Gallon per minute (GPM) required for the area under tower 3: 73.11
- Gallon per minute (GPM) required for the area under tower 4: 104.76
- Gallon per minute (GPM) required for the area under overhang: 47.05
- Fraction losses in tower 1 in feet: 0.782
- Fraction losses in tower 2 in feet: 0.715 Fraction

losses in tower 3 in feet: 2.601
- Fraction losses in tower 4 in feet: 1.256 Fraction losses in the overhang in feet: 0.157
- Total Pivot fraction loss in feet: 5.5116
- Flow velocity at the pivot point in feet per second: 2.74 Fraction losses in PVC mainline in feet: 9.73
- Flow velocity at the start of PVC mainline in feet per second: 4.23 Pivot Pressure in psi: 17.581
- Total dynamic head in psi: 47.77 Total dynamic head in feet: 110.34
- Pump horsepower (HP) requirement: 10.28

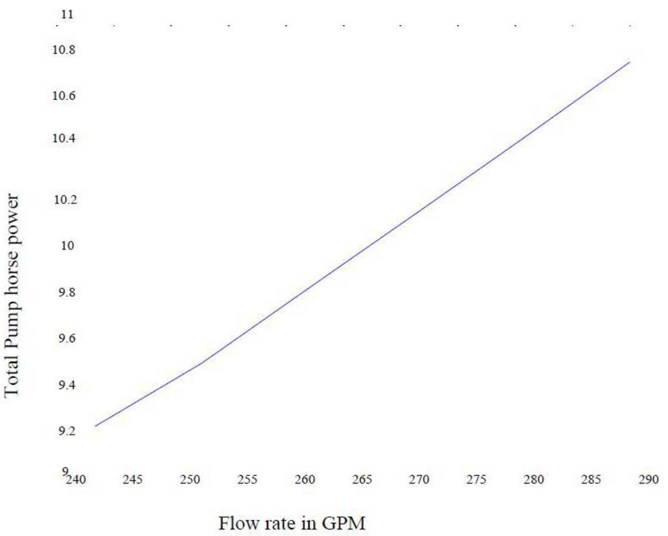

Figure 6: *Chart between flow rate and total pump horse power.*

Whereas;
Pump prime mover or motor horsepower (HP) requirement: 12.85; Pivot Horsepower requirement (HP) for Center drive unit motors: 5; Total Horsepower requirement (HP) for pump prime mover or motor and center drive unit motors: 17.85; Total KW requirement for pump prime mover or motor and center drive unit motors: 13.32; Total KVA requirement for pump prime mover or motor and center drive unit motors: 16.65; Total Amps requirement for pump prime mover or motor and center drive unit motors: 50.59

Figures 4 and 5 are showing the direct relationship between total dynamic head and flow rate and between the total dynamic head and pump horsepower. Thus, with the increase in total dynamic head, flow rate increases and when the increase in flow rate, there is an increase in horsepower of center pivot system.

Conclusions and Recommendations

The designed values were simulated with the actual values of the design parameters of HECPIS installed at NARC. The actual flow rate calculated at the field was 274 GPM while the designed value was 276.76 GPM, thus the accuracy of 99% was obtained. The designed total dynamic head was 110.34 feet, while the actual in the field was 108 feet. One of the reasons might be that the said HECPIS was installed in the year 2011, so after five years the pump efficiency would not be the same as it was in the early days. The actual amperage was calculated in the field and it meets the designed value.

The appreciable performance conditions are attributed to accurate design and installation of the system, scheduled maintenance and management among other factors. Pressure variations, clogging of sprinklers, rutting of un-graveled tracks are factors affecting the performance of the system and need to be reviewed although designed values were found within an acceptable range.

Acknowledgment

Authors would like to thank NARC, PARC, AEDB and PMAS Arid Agriculture University for their cooperation and providing necessary data and information.

Author's Contribution

Filza Fatima Rizvi was involved in Overall write-up, technical analysis of this paper and management of Research work.
Waqar khan contributed in technical input of whole research, in data collection and conceived the idea. Syed Mohsin Raza Kazmi;Overall formatting of paper proof reading,
Abstract review and Muhammad Umer worked in Proof reading,technical review
and in introduction and conclusion session.

Conflict of interests

The authors have declared no conflict of interest.

References

Abdellah, E.A., E. Ousama, A. Harkani and M. Mansouri. 2019. Modeling in Matlab/Simulink of a standalone photovoltaic pumping system for drip irrigation use and performance analysis.

Abdulrahman, A.I., 2006. Designing and developing an automated sprinkler irrigation system. Ph.D. thesis, Fac. Agric., Univ. Khartoum.

Agricultural Statistics of Pakistan, 2016-17. Agricultural Statistics of Pakistan 2016-17. Pakistan Bureau of Statistics. Retrieved from http://www.pbs.gov.pk/content/agricultural-statistics-pakistan

Ahmad, M.D., H. Turral, I. Masih, M. Giordano and Z. Masood. 2007. Water saving technologies: Myths and realities revealed in Pakistan's rice-wheat systems, Colombo, Sri Lanka. Int. Water Manage. Inst., 44: 415-425.

Ali, O., 2012. Performance of centre pivot irrigation systems in river nile state. Nat. Sci. 10(12): 184-187.

Ali, O., 2008. A Simulation model for Centre pivot irrigation system design and optimization of operation. Ph.D. thesis, Univ. Khartoum, Sudan.

American Society of Agricultural Engineers, 2000. Testing procedure for determining uniformity of water distribution of center pivot and lateral move irrigation machines equipped with spray or sprinkler nozzles. ASCE-S436.1, 48th Ed., St. Joseph, Mich.

Brennan, D., 2006. Water for a healthy country the economics of sprinkler irrigation uniformity: A case study of lettuce on the Swan coastal plain water for a healthy country the economics of sprinkler irrigation uniformity. A case study of lettuce on the Swan Coastal plain, (November).

Biswas, S. and M.T. Iqbal. 2018. Dynamic modelling of a solar water pumping system with energy storage. J. Solar Eng. 2018: 1–12. https://doi.org/10.1155/2018/8471715

Briscoe, J., U. Qamar, M. Contijoch, P. Amir and D. Blackmore. 2005. Pakistan's water economy: Running dry October 2005, (October), 1–140.

Camp, C.R., E. Sadler, D.E., Evans, L.J. Usrey and M. Omary. 1998. Modified center pivot system for precision management of water and nutrients. Appl. Eng. Agric., pp. 14. https://doi.org/10.13031/2013.19362

Claude, H.P., 1975. Application rates and uniformity of application from mechanical move sprinkler systems. Proce. Sprinkler Irrigation Tech. Conference, Atlanta, GA: 71-82.

Dechmi, F., E. Playán, J.M. Faci and M. Tejero. 2003a. Analysis of an irrigation district in northeastern Spain I. Characterisation and water use assessment. Agric. Water Manage., 61: 75–92. https://doi.org/10.1016/S0378-3774(03)00020-9

Dechmi, F., E. Playán, J.M. Faci, M. Tejero and A. Bercero. 2003b. Analysis of an irrigation district in northeastern Spain II. Irrigation evaluation, simulation and scheduling. Agric. Water Manage., 61: 93–109. https://doi.org/10.1016/S0378-3774(03)00021-0

Drahansky, M., M. Paridah, A. Moradbak, A. Mohamed, F. Owolabi, A. Taiwo, M. Asniza and S.H. Abdul Khalid. 2016. We are IntechOpen , the world ' s leading publisher of Open Access books Built by scientists, for scientists Top 1 %. Intech, I. (tourism), 13.

Farooq, U., M. Ahmad and A. Jasra. 2007. Natural resource conservation, poverty alleviation, and farmer partnership. Pak. Dev. Rev., 46(4), 1023-1049. Retrieved February 3, 2020. https://doi.org/10.30541/v46i4IIpp.1023-1049

FAO, 2012. FAOSTAT. Food and agriculture organization of the United Nations.

Foster, T., N. Brozović and A.P. Butler. 2014. Modeling irrigation behavior in groundwater systems. Water Res. Res., 50(8): 6370–6389. https://doi.org/10.1002/2014WR015620

GoP (Government of Pakistan). 2005. Medium term development framework 2005-10. Planning Commission, Islamabad, Pakistan.

GoP (Government of Pakistan). 2010. Discussion paper for people's five year development plan 2010-1015. Planning Commission, Islamabad, Pakistan.

GoP (Government of Pakistan). 2015. 2014-15 Economic survey of Pakistan. Ministry of finance division, economic advisor's wing, Islamabad, Pakistan.

Gbegbelegbea, D., F.S. Cammaranob, R. Assengb, U. Robertsonc, G.M. Chunga, H. Adamd, O.T. Abdallae, M. Paynea, K. Reynoldsa, B. Sondera, I.G.N. Shiferawa. 2017. Baseline simulation for global wheat production with CIMMYT mega-environment specific cultivars. Field Crops Res., 202: 122–135. https://doi.org/10.1016/j.fcr.2016.06.010

Gaudy, F., D. Howe's and D. Tom. 2007. Center pivot design for effluent irrigation of agriculture forage crops. Proc. Ann. Tech. Conf. Irrig. Assoc. pp. 1-16.

González Perea, R.,A. Daccache, J.A. Rodríguez

Díaz, E. Camacho Poyato and J.W. Knox. 2018. Modelling impacts of precision irrigation on crop yield and in-field water management. Prec. Agric, 19(3): 497–512. https://doi.org/10.1007/s11119-017-9535-4

IPCC. 2007a. Climate change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the IPCC. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, eds. Cambridge, UK: Cambridge Univ. Press. pp. 996.

IPCC. 2007b. Climate change 2007: Synthesis report. Contribution of working groups I, II and III to the Fourth assessment report of the intergovernmental panel on climate change. [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland. pp. 104.

IPCC. 2007c. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds. Cambridge University Press, Cambridge, UK. pp. 976.

Janani, P. and Saravanakumar, N. 2016. Automatic Field Irrigation Setup Using Matlab, IJARECE 5(2): 407–411.

Javaid, A., 2011. Effects of bio-fertilizers combined with different soil amendments on potted rice plants. *Chilean* J. Agric. Res., 71: 157-163. https://doi.org/10.4067/S0718-58392011000100019

Koech, R., M. Gillies and R. Smith. 2010. Simulation modelling in surface irrigation systems.

Li, Y., Y. Liu, H. Fan, X. Xing, L. Wu and X. Ma. 2019. Characteristics and simplified model of film slit irrigation. Arch. Agro. Soil Sci., 65(1): 16–30. https://doi.org/10.1080/03650340.2018.1477254

Moller, K., 2009. Influence of different manuring systems with and without biogas digestion on soil organic matter and nitrogen inputs, flows and budgets in organic cropping systems. Nut. Cycling in Agroecosyst., 84: 179-202. https://doi.org/10.1007/s10705-008-9236-5

PIPIP Project, P. 2012. World Bank

Sadati, S.K., S. Speelman, M. Sabouhi, M. Gitizadeh and B. Ghahraman. 2014. Optimal irrigation water allocation using a genetic algorithm under various weather conditions. Water (Switzerland), 6(10): 3068-3084. https://doi.org/10.3390/w6103068

Satoh, Y., T. Kahil, T., Byers, E., Burek, P., Fischer, G., Tramberend, S., Wada, Y. 2017. Multi-model and multi-scenario assessments of Asian water futures: the Water Futures and Solutions (WFaS) initiative. Ear. Future 5(7): 823-852. https://doi.org/10.1002/2016EF000503

United Nations Enviroment Program. 2012. the enviroment and climate change outlook of pakistan. UNEP (Vol. 91).

UNESCO, 2012. World Water Assesement program.

United Nations Conference on Sustainable Development, 2012. Migration and sustainable development. Rio 2012 Issues Briefs, No. 15.

Yan, P.S. and H.L. Xu. 2002. Influence of EM Bokashi on nodulation, physiological characters and yield of peanut in nature farming fields. J. Sus. Agric., 19: 105-112. https://doi.org/10.1300/J064v19n04_10