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Sustainable Water Management for Small Farmers with Center-Pivot Irrigation: A Hydraulic and Structural Design Perspective

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Abstract: In Pakistan, surface water supply for irrigation is decreasing, while water demand is increasing for agriculture production. Also, due to the fast rate of population growth, land holding capacity is decreasing. So, there is a need to develop appropriate technologies and design approaches for small-scale farmers to improve modern irrigation practices. In this study, a hydraulic and structural layout of CPIS was designed for small-scale farmers with some modifications. The hydraulic parameters and structural design of the CPIS were designed using IrriExpress and SAP2000 software, respectively. An economic analysis of the modified CPIS was carried out. The results revealed that in one complete revolution of the whole system, its span slope varied from 2.98 to 0.1%, and the wheel slope varied from 2.35 to −2.4%. The timing setting was 60% for one revolution, and the irrigation depth was 10 mm. When the time setting was reduced from 100% to 10%, the irrigation hours per cycle and irrigation depth both increased. Variendeel type-II trusses were designed for structural purposes using SAP2000 software. This design led to a 17% reduction in weight by lowering it from 1.916 to 1.5905 tons and a 44% reduction in joint count, decreasing it from 32 to 18. Our economic analysis revealed that the structural part of the system is more expensive than the hydraulic, electric and power parts for small-scale design. So, it was suggested that CPIS is suitable for land holdings from 100 to 250 acres, because when the area increases to more than 250 acres, there is no significant change in the cost. A towable system is more economical for small-scale farmers due to its lower cost per acre. This study will be helpful for the optimization of CPISs to improve water use efficiency and crop yield.

Keywords: HEIS; CPIS; SAP2000; IrriExpress; structural; hydraulic; cost estimation; small-scale farmers

1. Introduction

Pakistan is an agricultural country where 70 percent of water is used for crop production. Water availability is decreasing due to the increase in the crop area and change in rainfall patterns. Pakistan is on the verge of being categorized as a water-scarce nation, as the water availability per capita per annum in this country reduced from 5000 cubic meters in 1950 to 1100 cubic meters in 2010 [1]. The threshold for water-deficient countries is 1000 cubic meters per capita per annum. Moreover, the agricultural sector of Pakistan is currently facing issues related to financial limitations, an uneven supply of irrigation water, inadequate storage capacity and a great loss of water during irrigation. The irrigation system of Pakistan is based on the conventional techniques of irrigation, chiefly the flood basin technique [2]. More than 50% of irrigation water is wasted through these old techniques. The Indus Basin Irrigation is the principal irrigation network in the country. Though it irrigates 44 million acres of land, there are still some limitations which introduce deep flaws into this system. The inadequate framework for water disposal is the chief problem, in which a huge amount of water is wasted during irrigation. The irrigation efficiency is approximately 30 to 40 percent due to the use of conventional water application methods such as flooding (40–50 percent), furrow (50–60 percent), bubbler (60–70 percent), sprinkler (70–80 percent) and drip irrigation (80–90 percent) [3]. Due to the increased storage of water, the HEIS system is used for water saving. A common HEIS includes drip, sprinkler and center-pivot irrigation systems. The efficient use of water for agricultural production is highly emphasized by the Government of Pakistan due to the limited available water resources.

For sustainability, it is essential to create the right technology and design approaches to improve modern irrigation techniques, lower energy usage, increase water use efficiency and increase agricultural yields [4]. Micro-irrigation is generally regarded as one of the most effective and extensively used techniques, since it lowers water losses from evaporation in small regions where the topography is not always level. Several studies have concentrated on easy ways to create drip irrigation systems [5,6] and to reduce energy consumption [7,8]. To reduce both capital expenditures and operating expenses, many private enterprises are, however, investing in the mechanization of irrigation [9]. Globally, the usage of center-pivot irrigation systems (CPISs), particularly in recent decades, has grown dramatically, since it simplifies farm management, is just as effective as micro-irrigation but enables a much broader coverage, and takes less time than conventional irrigation methods [10–12]. Because of its automation, extensive coverage, dependability, uniform application and capacity to function on rather uneven topography, CPISs are replacing the irrigation systems that are now being utilized in relatively flat regions. According to irrigation scheduling, CPISs are far easier to automate and cost far less to operate than movable sprinkler systems that must be moved to different areas of the field [13]. Additionally, because center-pivots and lateral movements operate semi-automatically, it is quite simple to control the amount of water in the soil. Standard high-pressure (more than 350 kPa) impact sprinklers were installed on CPISs in the 1960s [14]. When the system nozzles were the right size and the pressure fluctuation along the lateral was within the acceptable bounds, these sprinkler packages had the benefit of a good application uniformity. Yet, because impact sprinklers demand a lot of energy, producers were quite concerned about rising energy prices in the 1970s [15]. The early 1980s saw the development of low-energy precision application (LEPA) and a low-pressure application package for center-pivot systems as a result [13]. In order to enhance the uniformity of the water application rate and to reduce the peak instantaneous precipitation rates, which may affect soil erosion, several studies on CPIS hydraulics have been conducted [16,17]. The irrigation system must apply enough water as it moves across the field to fulfil crop water demands until it irrigates that area of the field again; hence, center-pivots frequently provide water quicker than the infiltration rate. In order to calculate the friction losses along the CPIS, Reddy et al. [18] developed a correction factor. To describe the hydraulics of center-pivot laterals with and without the end-gun sprinkler, Scaloppi et al. [19] created mathematical equations. According to Faci et al. [20], who evaluated the effectiveness of rotating and fixed spray plate sprinklers, the rotating spray plate sprinklers placed at wider spacings along the lateral of the pivot have better homogeneity coefficients. As a result, it is possible to observe lower local instantaneous precipitation rate peaks and less unwelcome runoff, which limits the erosion processes that happen when the water application rate exceeds the soil infiltration capacity [21,22]. Valin et al. [23] created the DEPIVOT software program (Version 2.4), which enables the CPIS to be designed using five sub-models. Users can compare several sprinkler packages after verifying the basic target design parameters until the proper circumstances are obtained. Almeida et al. [24] developed a novel technology called localized mobile drip irrigation (IRGMO) in an effort to combine the benefits and practicalities of a center-pivot system with the effectiveness and water-saving capability of drip irrigation systems in order to maximize water usage efficiency. Almeida et al. [24] further observed that because drippers are so small, clogging occurrences can be more common than they are with sprinklers. Baiamonte et al. [25] recently examined the geometry of the watered zones of a CPIS fitted with rotating sprinkler guns, rather than the more typical drippers (IRGMO) or sprinklers. Clogging phenomena may be addressed using the larger-sized nozzles of CPIS sprinkler guns. The larger-sized nozzles on CPIS sprinkler guns may be able to address the plugging phenomenon. Because the sprinklers farther from the pivot move quicker and hence require higher instantaneous application rates, the CPIS controls the raising of the flow rates along the lateral to ensure the homogeneity of the water application rate. As a result, the irrigated area covered by a CPIS increases significantly with the system length. The manufacturers recommend using a semi-uniform spacing, which combines the previous two approaches, to irrigate the increased area while maintaining a constant application intensity. A semi-uniform spacing gradually reduces the spacing of equal-flow sprinklers along the center-pivot lateral [26]. The most popular strategy is to have sprinklers evenly spaced with increasing flow rates (nozzle sizes) along the center-pivot lateral, perhaps because it is simple to implement from a practical standpoint [26]. A constant spacing method is also used because it enables the sprinklers to be placed at key points along the lateral to ensure that the water distribution is equal.

As climate change continues to exacerbate water scarcity, the imperative to adopt high-efficiency irrigation systems over conventional methods is becoming increasingly evident. These advanced systems not only optimize water usage but also offer a sustainable solution to mitigate the growing challenges of resource depletion and environmental impact. The urgency to embrace these technologies has never been clearer, as we strive to safeguard our precious water resources in the face of climate-related challenges [27–30]. The need to create machines that are appropriate for each location and the need to gather data on the variability of soils, topography, infiltration rates, and microclimates within a field, as well as the anticipated crop water use patterns over the course of the season, could further complicate the design problem [7]. In conclusion, even though the technical literature has a wide variety of definitions and design processes, there is still no widely recognized design process. In reality, the topic of CPIS design is hotly contested, and farmers who utilize these systems still require clear, flexible design principles that emphasize maximizing water usage effectiveness and minimizing energy use. The objectives of this paper are (a) to investigate the hydraulic design of a CPIS, including the max. length of the lateral and sprinkler spacing, which also determines the head losses in a CPIS; (b) explore the structural optimization design of the center-pivot irrigation system; (c) and provide an economic analysis of the CPIS to optimize costs for small-scale farmers.

2. Materials and Methods

2.1. Study Area

In the hydraulic design of the center-pivot irrigation system, we defined the study area in IrriExpress (Version 1.5). The study area is "Dera Ghulam Muhammad Channar", located in the Bahawalpur region (Figure 1). The latitude and longitude range is 29°26′8.83″ N to 71°41′21.57″ E.

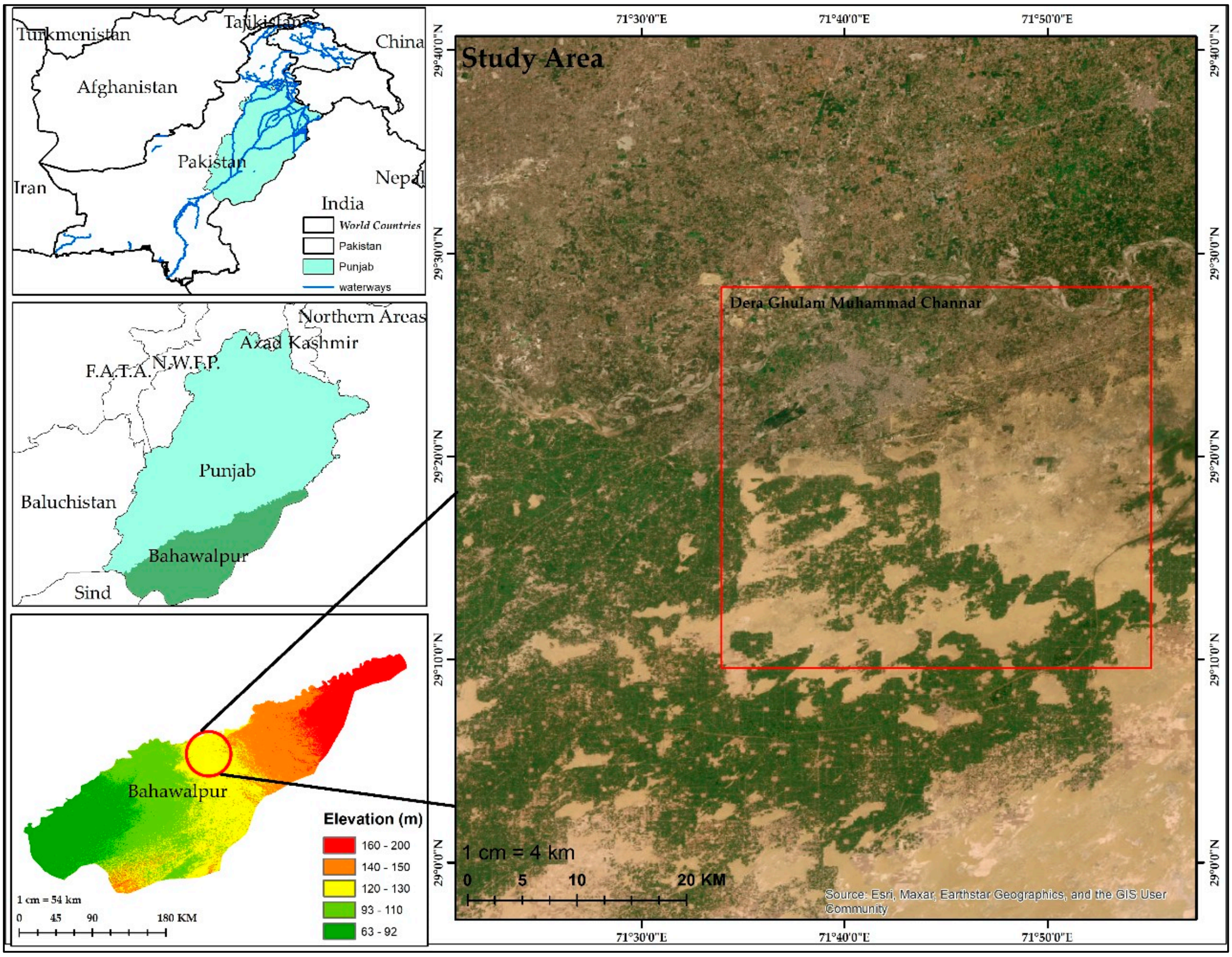


Figure 1. Study area map.

The hydraulic design of the center-pivot irrigation system was carried out using an Excel 2016 model and IrriExpress software, and the structural optimization design was carried out using SAP2000 (version 23.3.1). A methodology flow chart of the hydraulic and structural design of the center-pivot irrigation system is shown in Figure 2.

2.2. *IrriExpress*

Founded in 1963, IrriExpress is a type of software that allows one to create and validate irrigation designs in minutes. Using a simple, intuitive and powerful tool, one can create full irrigation projects using pivots, sprinklers and drips [31]. Imported Survey Data and DTM digital terrain modeling are available in IrriExpress. One opens the satellite image, selects the study area, and then imports it into the workspace. Digital terrain modeling provides information about the number of points, number of triangles and contour map of the study area. Computer-aided drawing shows information as lines, circles and images of the study area. The computer-aided drawing, or CAD (pivot), and digital terrain modeling DTM of the study area are shown in Figure 3. The total numbers of points and triangles of the study area in the CAD are 2040 and 3894. The digital terrain model for the center-pivot design is shown in Figure 3.

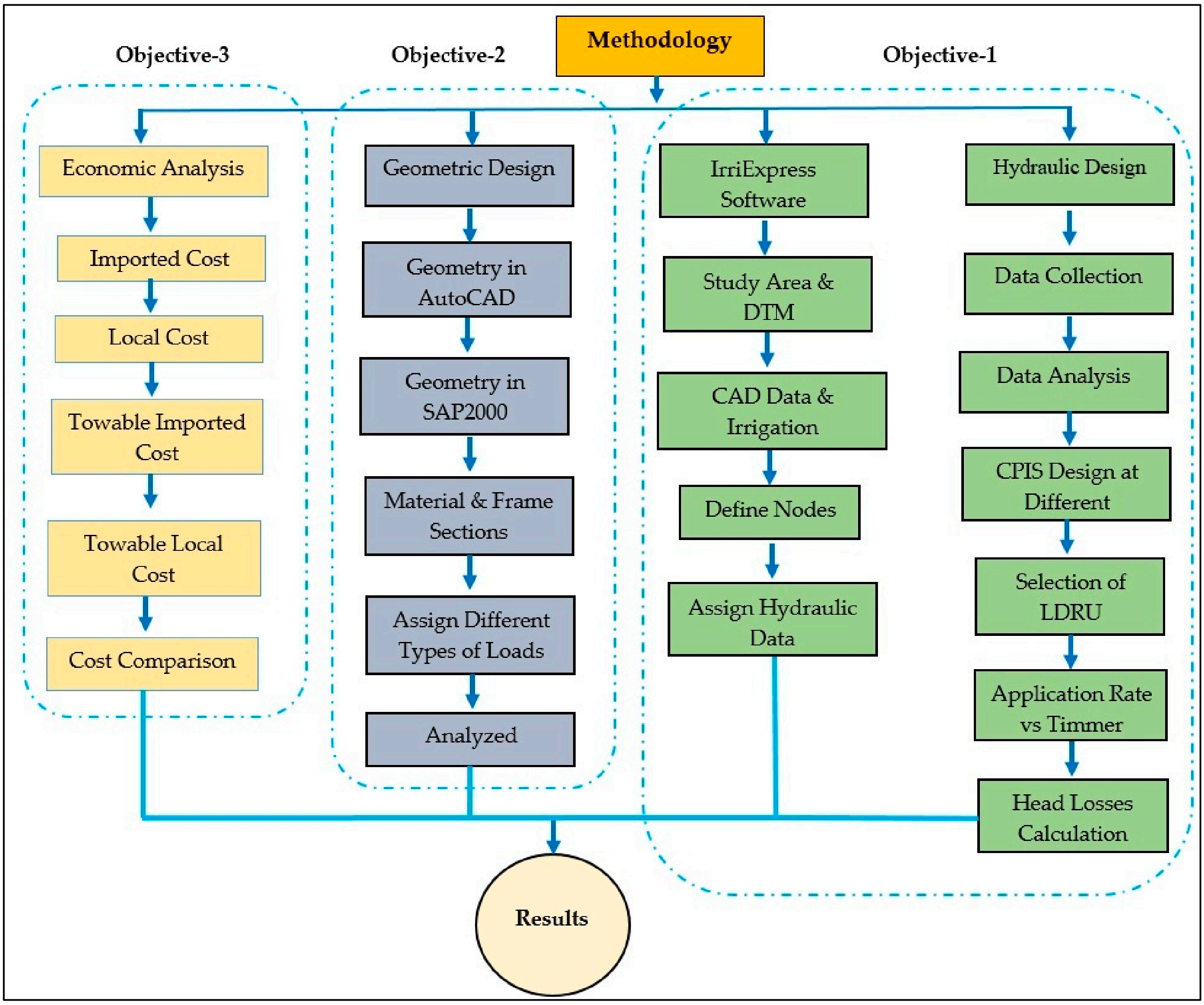


Figure 2. Methodology flow chart.

2.3. Structure of the CPIS in Irriexpress Software

The artistry of computer-aided drawing (CAD) unveils itself in the intricate depiction of the center-pivot irrigation system, an opus brought to life in Figure 3 With precision and foresight, diverse iterations of this pivotal structure, spanning across 5, 10, 15, 20, 25, and 30 acres, were elegantly crafted within the confines of IrriExpress. Here, the nodes and pumps conspire to marry the two sinuous pipelines in harmonious unity. A judicious fiscal approach is used to cast a singular pump as the steward of this hydraulic symphony, artfully employing a shift procedure to orchestrate the seamless irrigation transition between the adjacent CPIS pivots. The pump itself, with a maximum discharge of 1000 gallons per minute, takes on its role with aplomb, maintaining an average discharge of 500 gallons per minute.

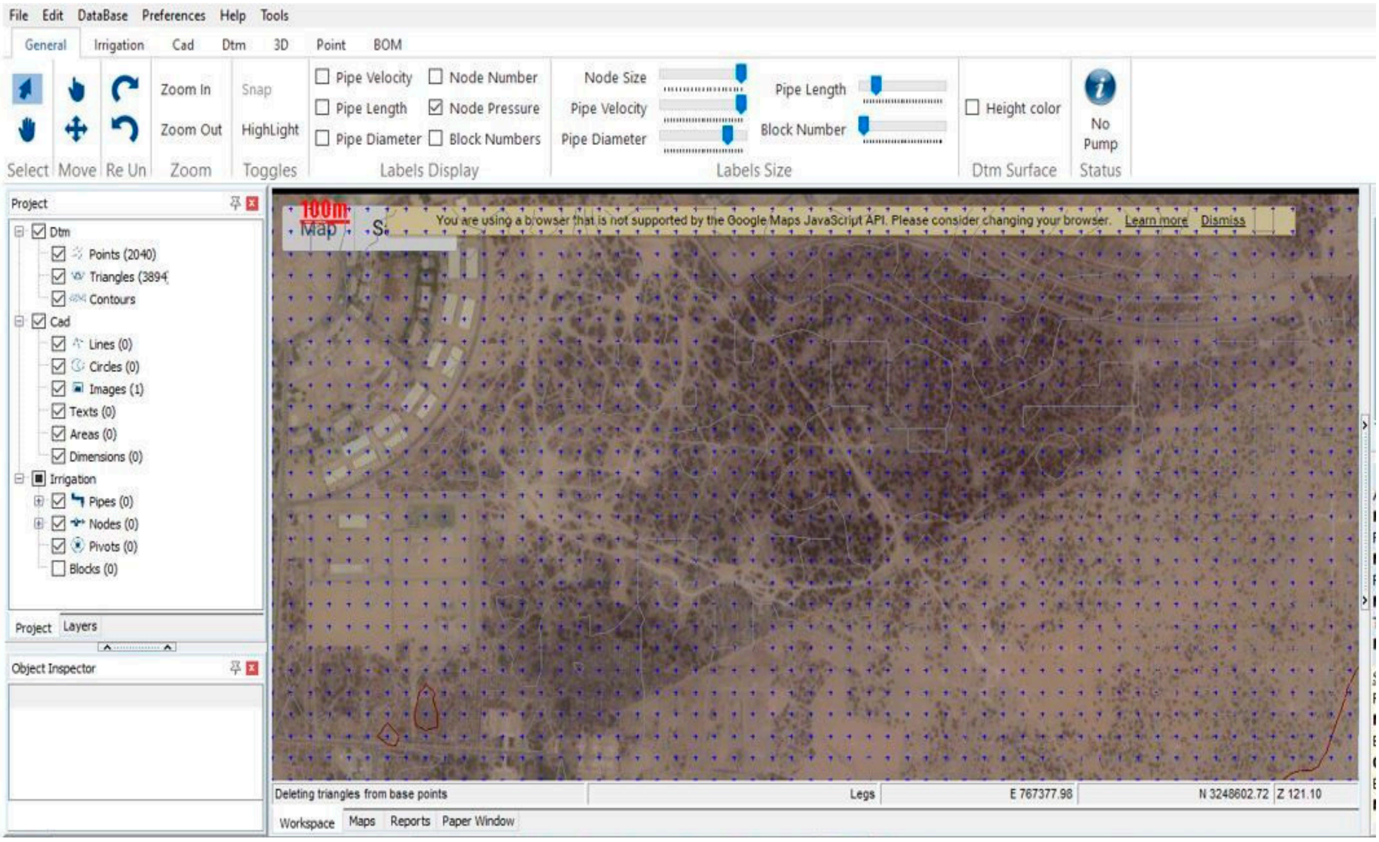


Figure 3. Digital terrain model of the CPIS in IrriExpress.

One defines the fundamental parameters of the system in this hydraulic design, creating a knowledge brocade. The number of spans, regulators and the count of sprinklers adorning each span all find their place within the dataset [32]. But beyond mere numbers, the dataset bears the imprint of hydraulic forces, offering a chronicle of pressures spanning from the inaugural span to the valedictory span in each pivot. However, before we embark on the grand analysis, an exposition of the hydraulic data unfolds. We meticulously traverse the domains of velocity, where the maxima and minima are artfully unveiled, alongside the zenith and nadir of pressure. This grand opera of data, intertwined with the sinuous paths of water distribution, promises a symphony of precision and a dance of hydraulic forces that delineate the essence of each CPIS.

The input hydraulic parameters of the center-pivot irrigation system used in IrriExpress software for different pivots are shown in Figure 4, depicting the pivot area, total length of the span and application rate required to complete one revolution. The application efficiency is 80% for all pivots, and the revolution time is 8 h for one circle. The moving speed of the latter is 10 m per second. The entire main line and span pipe are made of steel, and the value of the coefficient friction of the steel is 145.

The center-pivot design for 5, 10, 15, 20, 25 and 30 acres is shown in Table 1. In total, the span length includes the overhanging area and distance covered by the rain gun or end spray using the corner points. The total radius Ro of the CPIS is calculated by following Equation (1):

$$R_o = L_{sp} + r + r_1 \tag{1}$$

where R_o is the total radius covered by the pivot in m, *Lsp* is the span length of the pivot in m, r is the overhanging portion of the pivot in m, and r_1 is the end spray in m. The last wheel track circumference depends upon the total length of the span. The speed of each span is determined using the last wheel track. The prior pivot covers more space than the first pivot, as the radius of the span increases along with the pivot coverage area. The last wheel track circumference is calculated using Equation (2):

$$C_{wt} = 2\pi L_{sp} \tag{2}$$

where C_{wt} is the last wheel track circumference in m, and L_{sp} is the span length in m.

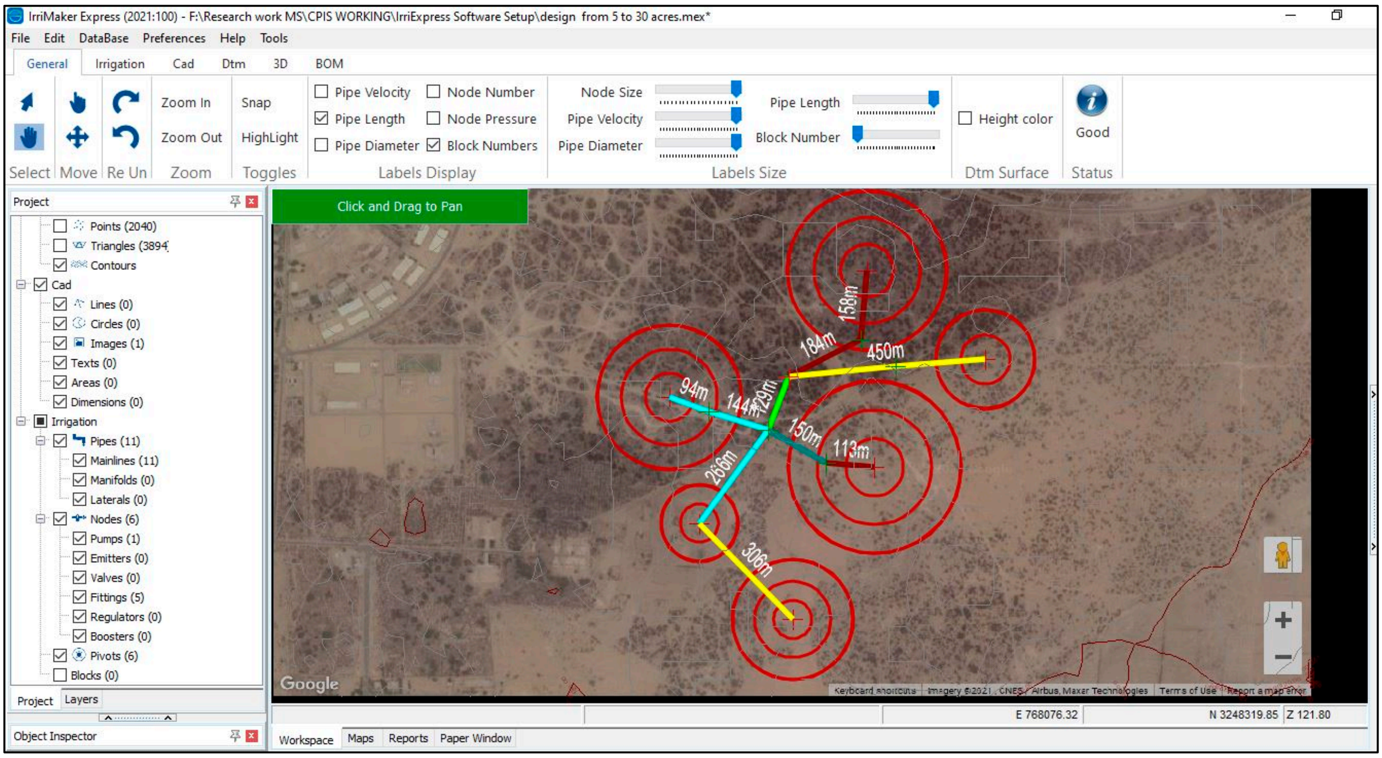


Figure 4. Computer-aided drawing of the CPIS with different sizes of pivots in IrriExpress.

Table 1. Hydraulic design of the center-pivot irrigation system.

Sr. No.	Field Area	Span Length	Overhanging Portion	No. of Spans	End-Gun	Radius Ro	Last Wheel	Application Rate	App. Time
	Acres	m	m		m	m	m	mm/Day	Hour
1	5.18	49.4	25.1	1	6.1	80.6	311.9	10	2
2	10.07	66.4	30.6	1	16.5	113.4	426.2	10	3
3	15.1	93.0	30.6	2	15.8	139.5	584.5	10	4
4	20.17	130.6	25.1	3	5.5	161.2	820.9	10	5
5	25.14	147.9	25.1	3	7.0	180.0	929.9	10	6
6	30.19	165.2	25.1	3	6.4	196.6	1037.7	10	6.5

The volume of water depends upon the gross depth required and area covered by the system. The total volume of each system is calculated using Equation (3):

$$V_w = D \times A \tag{3}$$

where V_w is the volume of water needed to irrigate a particular area, D is the gross depth, and A is the total system area. The discharge of the pivot depends upon the applied volume of water and application time for one revolution of the pivot. The total discharge is calculated using Equation (4):

$$Q = \frac{V_w}{T_a} \tag{4}$$

where the total discharge is measured in gallons per minute, the volume of water in cubic meters, and the time in hours for one pivot revolution.

The dynamic head includes the sum of the system's head losses, suction head, pressure regulator head and elevation head. The Hazen-Williams head loss Equation (5) was used to calculate the pipe head losses:

$$h\left(\frac{m}{100\text{m}}\right) = 1.22 \times 10^{12}\left(\frac{Q}{C}\right)^{1.852} \times (d)^{-0.438} \quad (5)$$

where h is the head loss in m for a 100 m pipe length, Q is the total discharge of the system in liters, C is the friction coefficient, the value of C for the steel pipe is 145, and d is the diameter of the pipe in inches. The power needed for this system was the final consideration in the CPIS's hydraulic design.

Equation (6) is used to compute the system's power:

$$P = \frac{Q \times H}{\eta} \quad (6)$$

where P is the total horsepower required for the system, Q = the total discharge of the system in gpm, H is the dynamic head in m, and η is the overall efficiency of the pump, which is 80 to 85% (Table 2).

Table 2. Output hydraulic parameters of the center-pivot irrigation system.

Field Area	Volume of Water	Total Discharge	Dynamic Head	Power of System
Acres	m^3	gpm	m	hp
5.18	210	462	22.31	18.88
10.07	407	599	22.82	22.19
15.1	611	673	29.49	28.28
20.17	816	719	29.99	29.97
25.14	1017	747	33.74	33.57
30.19	1222	823	34.6	36.79

2.4. Last Regular Drive Unit Setting

The last drive unit settings depend upon the last wheel track circumference, percent of slippage, rolling radius and tire size. The control panel contains the percent timer, a 60 s timer that controls the movement of the last tower, also known as the last regular drive unit (LRDU). If the percent timer is set to 100%, the last tower will travel indefinitely, and if the timer is set at 50%, the last tower will run for 30 s every minute. For the motors, one selects 2880 rpm for 5 acres to 30 acres. To find the last drive unit speed, first, one selects the motor rpm and C drive gear ratio and finds the C drive output:

$$CDO = \frac{M_{rpm}}{CDR_g} \quad (7)$$

where CDO = C drive output, M_{rpm} = motor revolutions per minute, and CDR_g = C drive gear ratio. The last regular drive unit speed rpm is 1.08 lower than the selected rolling radius of the tire. The tire size is 14.98*24, and the rolling radius is 146.57. The last drive unit speed and selected regular drive unit speed are calculated in Equation (8):

$$LRDUS = \frac{CDO}{CDR_g} \quad (8)$$

where LRDUS = last regular drive unit speed; CDO = C drive output; and CDR_g = C drive gear ratio.

$$SLDUS = \frac{M_{rpm} * LRDUS * R_r}{(1 - s)} \tag{9}$$

where SLDUS = selected last drive unit speed; M_{rpm} = motor revolutions per minute; LRDUS = last regular drive unit speed in m per minute; R_r = rolling radius of the tire in inches; and s = percentage of slippage. The selected regular drive speed is 4 m per minute. This means that if the timer setting is 100%, the last pivot will move continuously and cover a distance of 4 m in one minute, and if the timer setting is 50%, the last pivot will move for 30 s and covers a 2 m distance and then rest for 30 s. All the settings of the rmp and rolling radius of the last track wheel are shown in Table 3.

Table 3. Last regular drive speed setting of CPIS.

Motor	C Drive Gear Ratio	C Drive Output	LRDU Speed	Selected Last DU Speed	Tire Size	Rolling Radius	Key "Y" for Tire Selection	Selected Rolling R
RPM	#	RPM	RPM	m per min.	#	Inches	#	Inches
1458	51.47	28.3	0.54		11.2 ∗ 24″	130.25		
1750	51.47	34.0	0.65		10R ∗ 22.5″	123		
2880	51.47	56.0	1.08	4.00	11R ∗ 24.5″	131		
3500	51.47	68.0	1.31		14.9 ∗ 24″	146.57	Y	146.57
		136	2.62		16.9 ∗ 24″	156.2		
1750	40.69	43.0	0.83		11.2 ∗ 38″	172.55		

The timer setting of the last regular drive unit speed was set at 60% to ensure the required depth of water in one revolution of the pivot. This means that the last pivot moves for 40 s and 20 s at rest when the regular drive speed of the pivot is 4 m per minute. The time settings for 5 acres, 10 acres and 15 acres are shown in Table 4. To irrigate 5 acres in 2 h for one revolution of the pivot when the gross depth is 10 mm, the timer setting is 60%. Under the same conditions, for 10 and 15 acres, the time for full irrigation is 3 h and 4 h when the same gross depth of 10 mm is applied.

Table 4. Application rate verses timer setting of the last regular drive unit.

Timer Setting %	Hours per Full Irrigation Cycle	Gross Depth per Cycle	Timer Setting %	Hours per Full Irrigation Cycle	Gross Depthper Cycle	Timer Setting %	Hours per Full Irrigation Cycle	Gross Depth per Cycle
#	Hours	mm	#	Hours	mm	#	Hours	mm
100%	1.297	6.475	100%	1.747	5.818	100%	2.431	6.079
90%	1.441	7.194	90%	1.942	6.464	90%	2.701	6.754
80%	1.622	8.094	80%	2.184	7.272	80%	3.039	7.598
70%	1.853	9.250	70%	2.496	8.311	70%	3.473	8.684
60%	2.162	10.792	60%	2.912	9.696	60%	4.052	10.131
50%	2.594	12.950	50%	3.495	11.636	50%	4.862	12.157
40%	3.243	16.187	40%	4.368	14.544	40%	6.078	15.197
30%	4.324	21.583	30%	5.825	19.393	30%	8.103	20.262
20%	6.486	32.375	20%	8.737	29.089	20%	12.155	30.394
10%	12.972	64.749	10%	17.474	58.178	10%	24.310	60.787
Water app. vs. Timer Setting for 5 Acres			Water app. vs. Timer Setting for 10 Acres			Water app. vs. Timer Setting for 15 Acres		

Table 4. *Cont.*

Timer Setting %	Hours per Full Irrigation Cycle	Gross Depth per Cycle	Timer Setting %	Hours per Full Irrigation Cycle	Gross Depthper Cycle	Timer Setting %	Hours per Full Irrigation Cycle	Gross Depth per Cycle
#	Hours	mm	#	Hours	mm	#	Hours	mm
100%	3.414	6.831	100%	3.865	6.445	100%	4.316	6.639
90%	3.794	7.590	90%	4.295	7.161	90%	4.796	7.377
80%	4.268	8.539	80%	4.831	8.056	80%	5.395	8.299
70%	4.877	9.758	70%	5.522	9.207	70%	6.166	9.485
60%	5.690	11.385	60%	6.442	10.741	60%	7.194	11.065
50%	6.828	13.662	50%	7.730	12.889	50%	8.632	13.278
40%	8.536	17.077	40%	9.663	16.112	40%	10.790	16.598
30%	11.381	22.770	30%	12.884	21.482	30%	14.387	22.131
20%	17.071	34.155	20%	19.326	32.223	20%	21.581	33.196
10%	34.142	68.309	10%	38.652	64.446	10%	43.162	66.392
Water app. vs. Timer Setting for 20 Acres			Water app. vs. Timer Setting for 25 Acres			Water app. vs. Timer Setting for 30 Acres		

The irrigation time for one complete revolution of the pivot and gross depth are calculated using the following equations:

$$T_i = \frac{C_{wt}}{LDUS * TS.} \quad (10)$$

where T_i = the irrigation time for one complete revolution in hours; C_{wt} = last wheel track circumference in m; LDUS = last drive unit speed in m per minute; and TS = timer setting as a percentage.

$$D = \frac{T_i * A}{Q} \quad (11)$$

where D = gross depth applied in mm; A = total area covered by the pivot in acres; and Q = total discharge of the system in gpm.

2.5. Structural Design of Center-Pivot Irrigation System

An important objective of this research is to foster a local capability to develop a CPIS suitable for Pakistan. A detailed structural analysis and design were performed using SAP2000 for the complete structural supporting system of this machine, considering all the envisaged loadings [33]. This included the preparation of fabrication drawings, including vertical flexibility details and the rotation assembly. A small-scale model of the CPIS was developed to demonstrate the design's workability, giving due importance to structural similitude. At the end of this process, a cost comparison was performed between the imported structural system of the CPIS and locally fabricated structural system of the CPIS [34]. The final topology for this sprinkler system to be adopted in Pakistan is a Vierendeel truss based on constructability, architectural requirements and local suitability considerations. This 200 ft long truss has a center crown height of 12 ft. The spread of the truss at the central bay is 12 ft. The truss stretch has seven equal spans.

2.5.1. Analysis and Design of Center-Pivot

The complete structure of the CPIS was modeled in SAP2000 for a structural design based on the envisaged loadings. All components of a center-pivot irrigation system, like the pivot point, drive unit, main pipes, trusses and rebar design, were modeled in AutoCAD and then imported into SAP2000 software. The finite-element model of the system is shown in Figure 5.

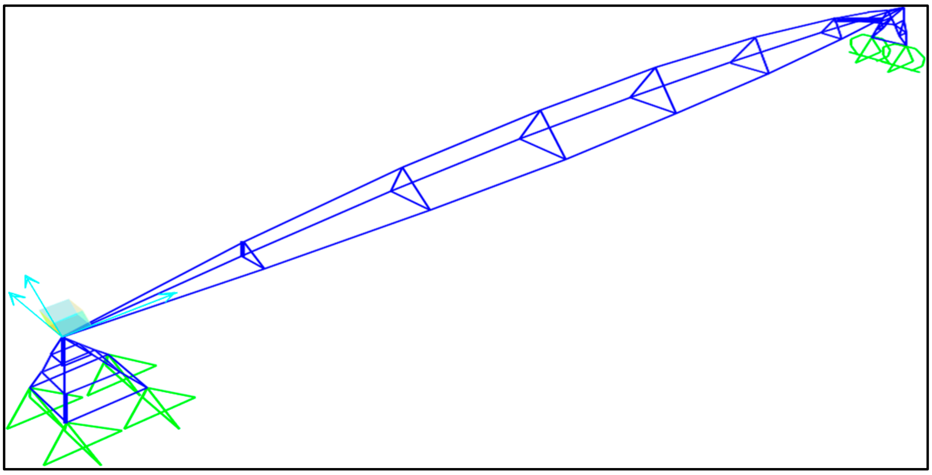


Figure 5. Finite-element model of CPIS structural system.

2.5.2. Model Definition

The CPIS model was developed using 168 frame elements and 91 joints. A36 material and grade-60 rebar materials were defined. The frame sections for the HSS 5 × 0.258 pipe were added and assigned to the top chord line elements. The bottom tension chord was assigned solid rebar frame sections. All the diagonal and vertical braces constituted angle frame sections.

2.5.3. Load Considerations

The following array of loading scenarios was meticulously delineated, adhering closely to the AISC LRFD 2010 code's prescribed load combinations, which were meticulously orchestrated to underpin the analysis and structural design: dead, live, water and wind.

In the realm of truss structures, a characteristic trait of the surfaces is that the transmission of bending moments across the joints largely remains absent. Here, every member bears the mantle of the frame releases at both termini, artfully alleviating the burden of the bending moments. Yet, in the unique tapestry of the Vierendeel truss, a paradigm shift emerges [35–37]. Its very essence, a requirement for kinematic stability, necessitates an inherent rigidity at the juncture of the top chord members and diagonals. This implies that the modest magnitude of the bending moments from the top chord must, with care, be transferred to the diagonal members. With meticulous precision, essential property modifiers were seamlessly applied through the medium of the software. The labor of computation ensued, birthing member forces meticulously computed for each member and threading the intricate web of load cases and combinations into a coherent narrative.

In the latter segment, the steel members embarked upon a journey of design, ensconced within the sanctuary of the governing load combinations, carefully shepherded by the tenets laid forth in the AISC LRFD 2010 code. As the narrative unfolds, we find ourselves at the threshold of the development of a scale model. This is no mere coincidence but a calculated choice, one that emerges from an array of potential topologies, with the Vierendeel truss gracefully claiming its place as the selected archetype. This decision, intricately woven into the overall optimization hierarchy, stands as a testament to its merit. Figure 5 serves as the visual embodiment of this choice, reflecting a harmonious synergy of form and function. In our pursuit of precision, the variegated truss parameters and the truss's performance, artfully distilled into the elements of fitness value, deflection and stress, stand as stoic sentinels in Table 5, meticulously chronicling the essence of our creation.

Table 5. Sizes of different elements of the CPIS in a scale model.

Description	Dimension	Actual Structure	Specification
Span Length	ft	200	
Top Chord	inches	5	Galvanized A36 Steel Pipe
Bottom Chord	inches	3/4 dia. of Rebar	Diameter of Rebar
Ribs	inches	$2 \times 2 \times 1/8$	Angle Section
Tower Members	inches	$4 \times 4 \times 1/4$	Angle Section
Motor	RPM	2880	0.75 hp, One Motor Required
Pump Discharge	gpm	461.2	
Rotating Mechanism		Bearings	
Wheels	inches	$14.9 * 24''$	Diameter of Rubber Wheel

2.5.4. Physical Properties of the Scale Model

Axial stresses dominate the structural response for truss-type structures. First-order similarity, considering the fundamental parameters, is allowed for models, such that the response of the prototype and model remains proportional (Table 6).

Table 6. Different physical properties and their values for the scale model.

Description	Prototype
Internal Diameter (mm)	127.00
Outer Diameter (mm)	140.1
Cross-sectional area (mm^2)	2749.52
MOI (mm^4)	6,144,976.42
Length (mm)	10,000
Line load (kg/m)	43.17
Axial Force	618,642.5
Axial Stress	225

2.5.5. Material Selection

The locally fabricated CPIS can be created with ASTM A36 steel, a material available on the market (Table 7).

Table 7. Mechanical properties of material selected for the scaled model.

Mechanical Properties	Material A36
Modulus of Elasticity, E (Mpa)	200,000
Tensile Strength (Mpa)	400
Yield Strength (Mpa)	250
Shear Modulus (Mpa)	75,000
Poisson's Ratio	0.32

2.5.6. Fitness Function

The objective of optimization was to minimize the mass of the truss while satisfying the strength and serviceability criteria. For this purpose, the fitness function was used to penalize the solutions which violated the performance targets. The fitness function to be minimized is expressed in Equations (12) and (13):

$$f(x) = \sum_{i=1}^{N} \rho A_i L_i + PF \tag{12}$$

where the first term represents the mass of the truss, and *PF* is the penalty function.

$$F = \alpha \left[\left(\frac{|\sigma max|}{\sigma_{all}} - 1 \right)^2 \right] + \beta \left[\left(\frac{|\mu 1|}{u_{all}} - 1 \right)^2 \right] \tag{13}$$

The value of α, a penalty coefficient for the stress limit, is set to 0 when no stress condition is violated and set to 103 otherwise. In a similar manner, the value of β, a penalty coefficient for the serviceability limit, is fixed between 0 and 103. $\sigma_{max}/\sigma_{all}$ is the stress demand to capacity ratio, i.e., the summation of the ratio of maximum axial stress in the individual truss to the nominal axial strength of this element and the ratio of its flexural stress to its nominal flexural strength. μ is the maximum vertical displacement of the midpoint of the truss, and μ_{all} is the maximum allowable vertical displacement of the truss. The dead, live, water, wind and coating loads were defined. The AISC LRFD 2010 code load combinations were used for the analysis and design of the structure. The member forces for each member were calculated for each load case and load combination. In the second part, the steel members were designed based on the governing load combination, as per the AISC LRFD 2010 code.

2.6. Cost Estimation of the Center-Pivot Irrigation System

The cost comparison between the imported structural system of the CPIS and locally fabricated structural system of the CPIS is shown in Table 8. To establish a common basis of comparison, the costs incurred for the installation of the structural system of the CPIS are considered. The costs of the operational equipment and other electro-mechanical devices are considered. The cost of the CPIS for 5, 10, 15, 20, 25 and 30 acres is shown below in Table 8. This cost includes the sprinklers, flow meter, pressure regulators, venture, fertigation injector pump, pressure gauges, mechanical drive network, electric distribution network, installation charges, transportation charges, water filter, fertilizer tank, PVC pipes, fittings and pumps, but it does not include the generator, water supply tank or well.

Table 8. Cost estimation of the imported and local development systems of the CPIS.

Field Area	No. of Spans	Import Cost	Per Acre Import Cost	Local Cost	Per Acre Local Cost	Cost Difference	Per Acre Difference
Acres	**#**	**Million INR**	**Million INR**	**Million INR**	**Million INR**	**Million INR**	**Million INR**
5	1	3.99	0.79	3.19	0.64	0.79	0.16
10	1	5.73	0.57	4.59	0.46	1.14	0.12
15	2	9.99	0.66	7.99	0.53	1.99	0.13
20	3	11.9	0.56	9.03	0.45	2.26	0.11
25	3	11.8	0.474	9.47	0.38	2.37	0.095
30	3	13.7	0.457	10.9	0.37	2.743	0.091

Due to the high structure cost of CPISs, small-scale farmers do not purchase them for small areas. To reduce the cost of CPISs for small-scale farmers, a towable center-pivot system is preferred. Towable irrigation systems may manage water in one to four neighboring fields and are typically smaller than permanent irrigation systems. When rainfall is inadequate for good crop production, these systems are often utilized as supplemental irrigation in humid climates and in many fields. During seasons of drought, the machine is usually moved at least once a day. The costs of a towable CPIS for 5, 10, 15, 20, 25 and 30 acres are shown below in Table 9. The cost includes the sprinklers, flow meter, pressure regulators, venture, fertigation injector pump, pressure gauges, mechanical drive network, electric distribution network, installation charges, transportation charges, water filter, fertilizer tank, PVC pipes, fittings, pumps and moving system used for a towable CPIS, but the cost does not include the generator, water supply tank or well.

Table 9. Imported and local cost estimation of a towable CPIS.

Field Area	No. of Spans	Towable Area	Import Towable Cost	Per Acre Import Cost	Local Towable Cost	Per Acre Local	Cost Difference	Per Acre Cost Difference
Acres	#	Acres	Million INR	Million INR	Million INR	Million INR	Million INR	Million INR
5	1	20	4.99	0.249	4.241	0.212	0.748	0.037
10	1	30	7.1	0.234	5.978	0.199	1.055	0.035
15	2	45	11.5	0.255	9.764	0.217	1.723	0.038
20	3	60	12.9	0.215	10.949	0.182	1.932	0.033
25	3	75	13.8	0.185	11.767	0.157	2.076	0.028
30	3	90	15.8	0.176	13.444	0.149	2.373	0.027

3. Results and Discussion

3.1. Hydraulic Design

The hydraulic design results are calculated using the valley irrigation model and IrriExpress hydraulic design software [38]. The last cost estimation of the CPIS is calculated on a different scale, comparing the imported and local costs of the CPIS. The per acre cost does not change.

IrriExpress software was used for the hydraulic design of the CPIS. IrriExpress calculates all the parameters of the center-pivot irrigation system, like the CAD data, DTM data, nodes, irrigation, etc. IrriExpress provides the results of all spans of the CPIS in one system. In the Methodology section, all the input hydraulic parameters which are required in the IrriExpress software are mentioned. The input hydraulic parameters are shown in Table 1.

3.2. Node Pressure of Center-Pivot

The hydraulic pressure at the nodes of the pivots is shown in Table 10. The maximum pump pressure is 120.80 psi, and the maximum elevation is 122.4 m [4]. The minimum pressure for pivot number 6 is 101.77 psi, and the maximum pressure for pivot number 4 is 118.47. All available pressure values from pivot no. 1 to pivot no. 6 are shown in Table 10.

Table 10. Node pressure of the0 CPIS in IrriExpress.

Mainline	Name	Description	Elevation	Flow	Pressure Needed	Pressure Available
#	#	#	(m)	gpm	psi	psi
2	Shift #1	Medium (50)	122.4	2937.21	120.8	120.8
3	Pivot 1	Valve	122.8	717.79	85.27	116
4	Pivot 2	Valve	121.1	522.89	85.27	115.41
5	Pivot 3	Valve	123.4	276.93	85.27	112.12
6	Pivot 4	Valve	121	841.79	96.8	118.47
12	Pivot 5	Valve	120.3	166.83	85.27	114.56
13	Pivot 6	Valve	121.9	410.97	85.27	101.77

3.3. Pipe Velocity Variation for All Pivots

The minimum and maximum velocity of the first pivot to the last pivot changed from 1.1 to 2 m per second (Table 11). The minimum and maximum pressure changed from 101.8 to 120.8 psi [39].

Table 11. Velocity variation of different pivots in IrriExpress.

Pivot Number	Max. Pipe Velocity	Min. Pipe Velocity	Max. Node Pressure	Min. Node Pressure	Remarks
#	m/s	m/s	psi	psi	#
Shift # 1	2	1.1	120.8	101.8	Good
Pivot 1	2	1.1	120.8	101.8	Good
Pivot 2	2	1.1	120.8	101.8	Good
Pivot 3	2	1.1	120.8	101.8	Good
Pivot 4	2	1.1	120.8	101.8	Good
Pivot 5	2	1.1	120.8	101.8	Good
Pivot 6	2	1.1	120.8	101.8	Good

3.4. Maximum Span Slope

The angle at which a center-pivot irrigation system's (CPIS) main pipeline or span is positioned in relation to the ground is known as the span slope, and it is essential for guaranteeing an even water distribution across the field. CPIS operators can adapt the system to their field's unique topography by adjusting the span slope angle, which will enable effective irrigation and save water. To maximize crop coverage, one minimizes runoff and encourages the effective use of water resources in agriculture. Span slope modification is important. Center-pivots were designed to accommodate land holdings of 5, 10, 15, 20, 25 and 30 acres. The maximum span slope was 2.9, 1.8, 1.6, 2, 1.4 and 1.3% for 5, 10, 15, 20, 25 and 30 acres, respectively (Figure 6).

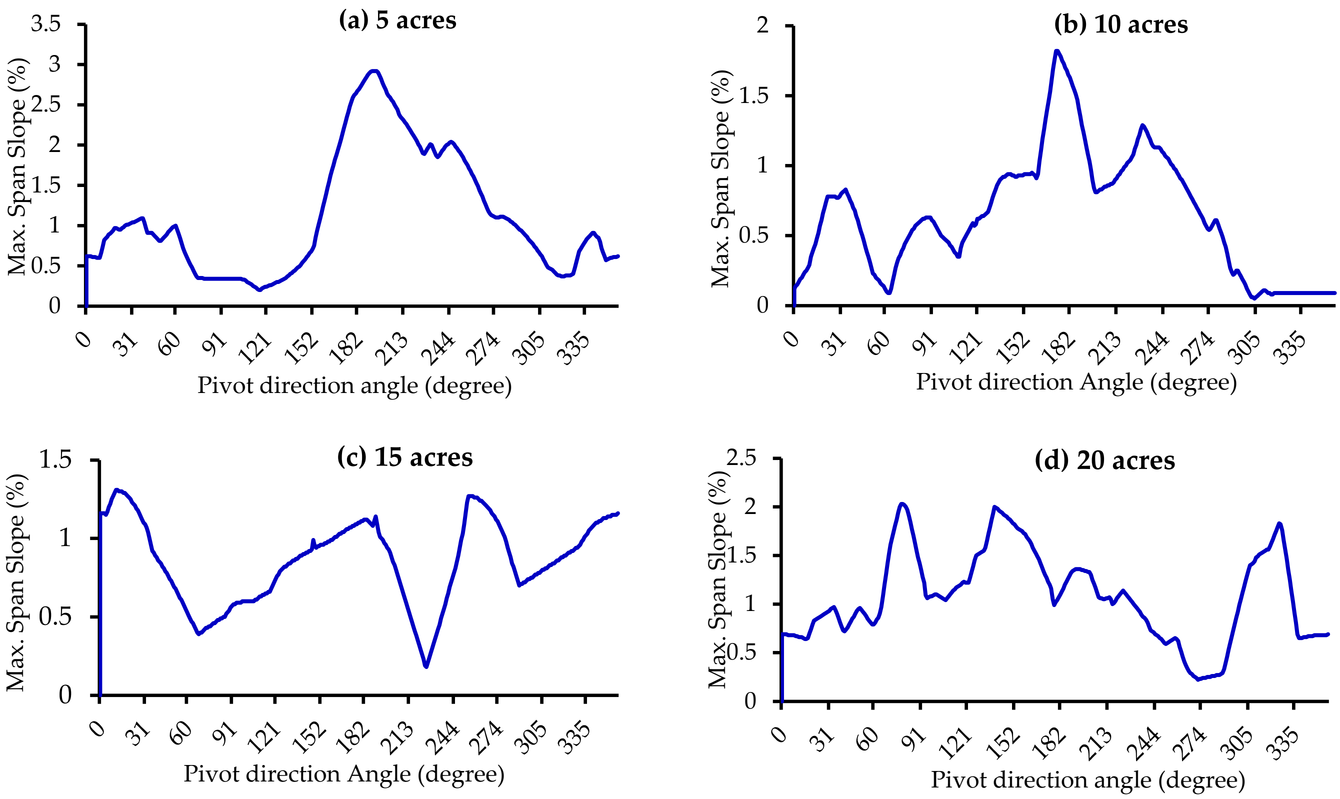


Figure 6. *Cont.*

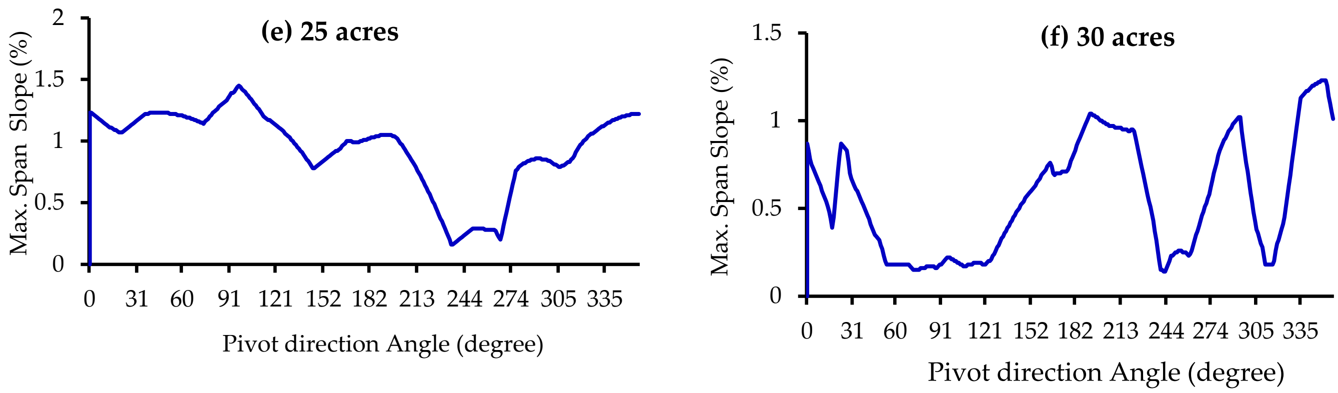


Figure 6. Maximum span slope of the center-pivot irrigation system for 5, 10, 15, 20, 25 and 30 acres.

3.5. Maximum Wheel Slope

The inclination at which the wheels of a center-pivot irrigation system (CPIS) are positioned with respect to the ground is known as the wheel slope. The CPIS structure is entirely supported by these wheels, which also enable the system to move more easily as it spins in a circle over the field. The wheel slope angle is a crucial design factor, since it guarantees the stability and effective terrain navigation of the CPIS. The CPIS can react to changes in ground elevation and contour by changing the wheel slope, which keeps it stable and balanced while in use. In particular, when working, properly adjusting the wheel slope is crucial for avoiding problems like equipment tipping or uneven irrigation distribution. The maximum wheel slope for a 5-acre center-pivot irrigation system (CPIS) was 2 percent, while the 10-acre CPIS exhibited a wheel slope of 1.8 percent. In the case of a 15-acre CPIS, the wheel slope measured at 2.8 percent, and for a 20-acre CPIS, it was 2.5 percent. The 25-acre CPIS had a wheel slope of 2.2 percent, and for the 30-acre CPIS, the wheel slope reached 2.8 percent (Figure 7).

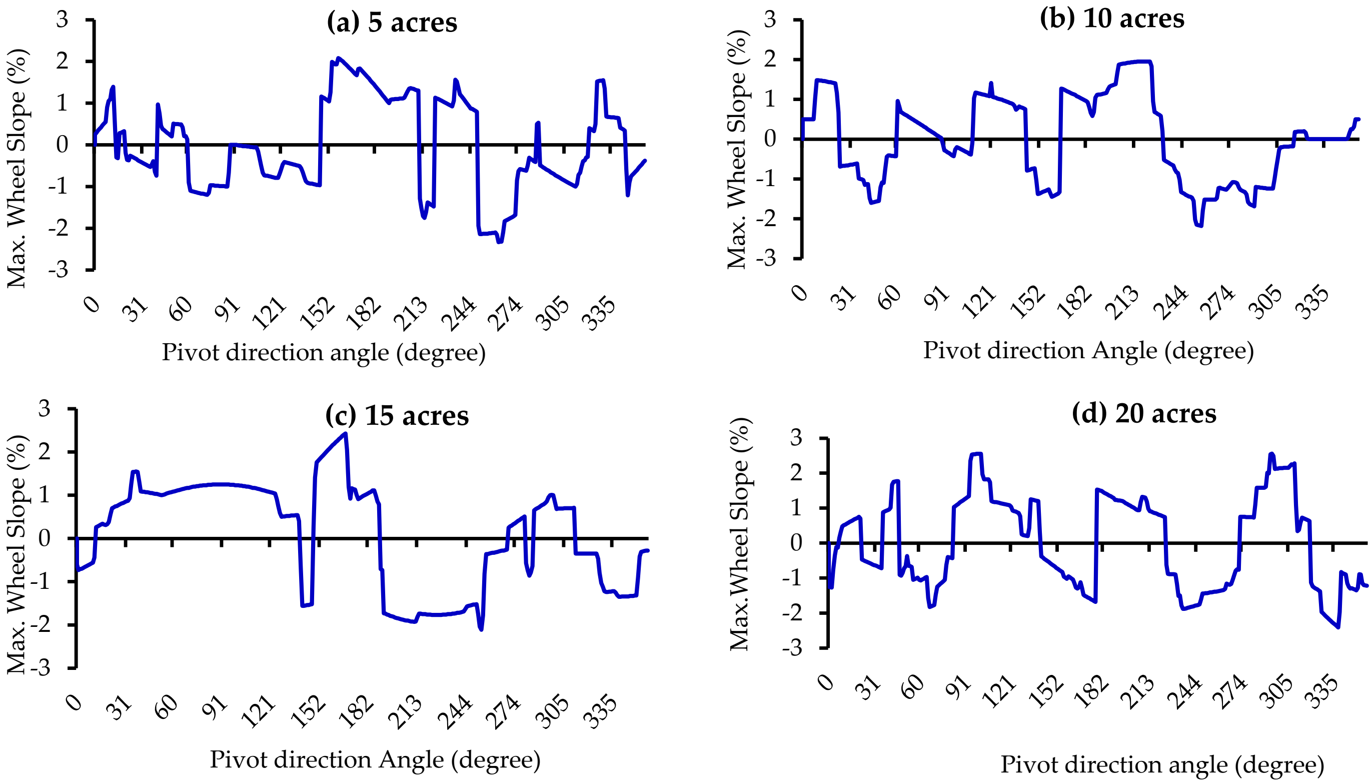


Figure 7. *Cont.*

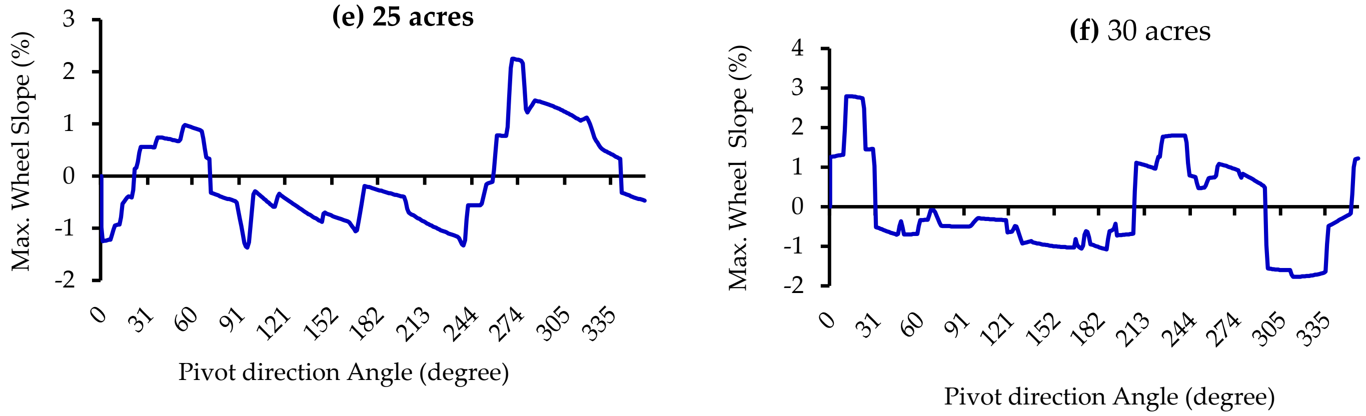


Figure 7. Maximum wheel slope of the center-pivot irrigation system for 5, 10, 15, 20, 25 and 30 acres.

3.6. Maximum Twist Angle

The maximum degree of angular rotation or twisting that the structure of a CPIS can accomplish without compromising its structural integrity and performance is known as the maximum twist angle. It represents the system's ability to adjust to the shifting topography by allowing it to twist or pivot at its joints as it travels in a circle over the field. The CPIS's ability to handle difficult or irregular terrain and maintain its ability to deliver water uniformly to the crops makes the maximum twist angle a crucial design feature. This is a concern that CPIS designers and operators need to take into account in order to avoid structural damage, operational problems and interruptions in irrigation activities. The maximum twist angle observed was 1.5 percent in a 20-acre area, while the lowest twist angle observed in a 25-acre area was 0.8 percent. The variation in the twist angle for 5, 10, 15, 20, 25 and 30 acres is depicted in Figure 8.

3.7. Structural Design

The structure of the center-pivot irrigation system was designed using SAP2000 structural software. In this section, the results regarding truss optimization, complexity reduction, weight optimization and cost reduction are presented.

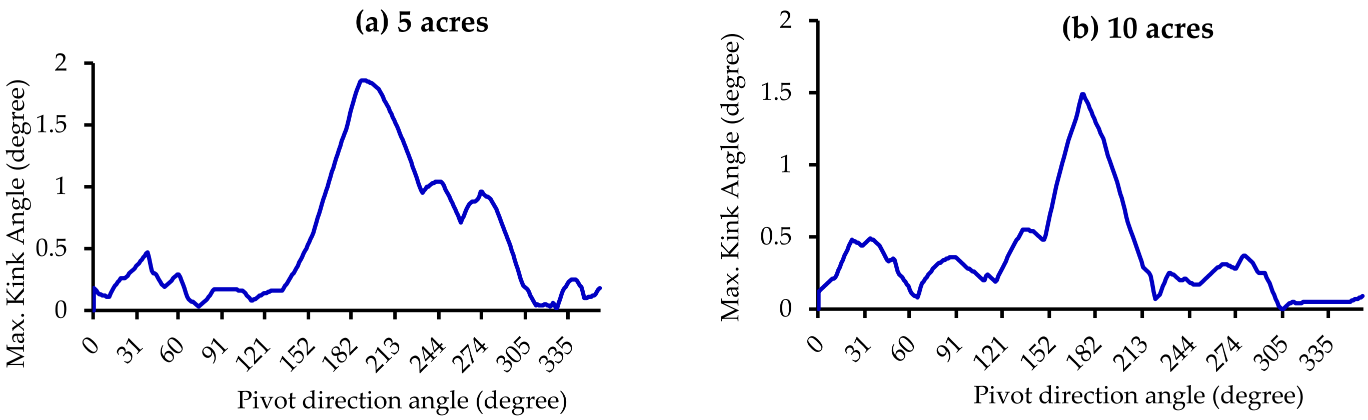


Figure 8. *Cont.*

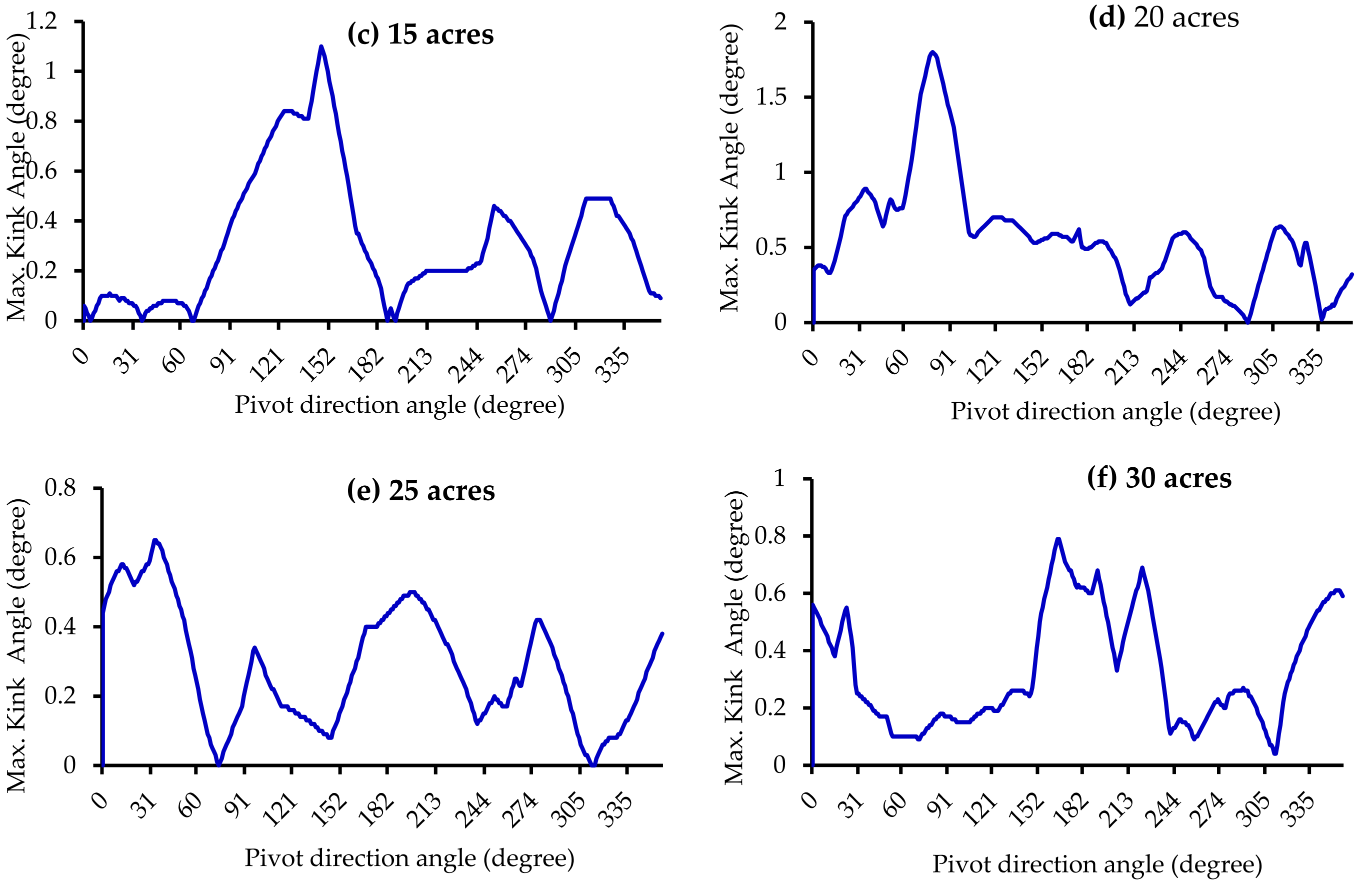


Figure 8. Maximum twist angle of the center-pivot irrigation system for 5, 10, 15, 20, 25 and 30 acres.

3.7.1. Structural Optimization of CPIS Trusses

The results regarding the structural optimization of the CPIS truss, with the contribution of various design variables, are illustrated in Table 12. The performance targets, also explained in this session, include the strength and serviceability criteria. The values of different performance targets for each top-performing truss are given adjacent to the truss geometry. The maximum weight of the Vierendeel type-II truss was 1590 Kg, the stress ratio was 0.98, and the maximum displacement was 165 mm.

The Vierendeel type-II truss shown in Figure 9 was selected for final development because it has fewer joints and a lower weight [40]. Based on the list of the best-performing shapes listed in Table 12, this truss comes in second place. Moreover, maintaining the height to spread ratio, the angle between the vertical web member and horizontal web member remains same [41]. The plate connections shall therefore remain the same, further simplifying the fabrication process. Figure 9 shows both the final optimal solution and the evolution of the ideal solution over time.

Table 12. Results for optimization, showing the values of various performance targets for every variation in truss shape.

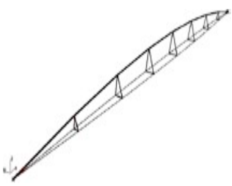
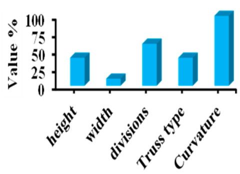
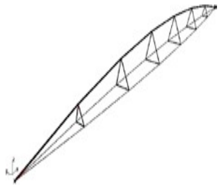
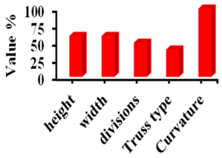
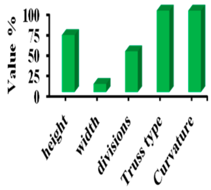
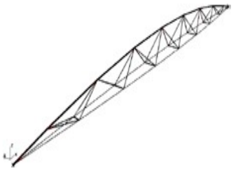
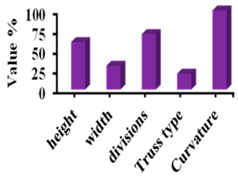
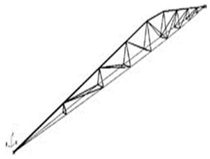
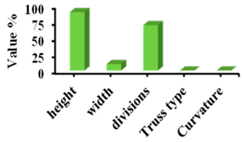
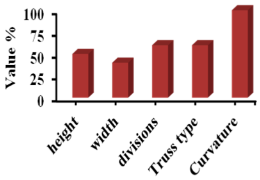
Fitness Rank	Truss Geometry	Design Variable Plot	Parameters	Values
1-Vierendeel Type 1 Truss			Weight Kg (lbs) Max. Displacement mm (in) Max. Stress (D/C Ratio)	1560 (3438) 237 (9.33) 0.89

Table 12. *Cont.*

Fitness Rank	Truss Geometry	Design Variable Plot	Parameters	Values
2-Vierendeel Type 2 Truss			Weight Kg (lbs) Max. Displacement mm (in) Max. Stress (D/C Ratio)	1590 (3504) 165 (6.5) 0.98
3-U Pratt Type Truss			Weight Kg (lbs) Max. Displacement mm (in) Max. Stress (D/C Ratio)	1803 (3974) 147 (5.8) 0.99
4-Warren Type Truss			Weight Kg (lbs) Max. Displacement mm (in) Max. Stress (D/C Ratio)	1820 (4011) 168 (6.6) 0.86
5-Pratt Type Truss			Weight Kg (lbs) Max. Displacement mm (in) Max. Stress (D/C Ratio)	1840 (4055) 229 (9) 0.92
6-Brown Type Truss			Weight Kg (lbs) Max. Displacement mm (in) Max. Stress (D/C Ratio)	1980 (4365) 218 (8.6) 0.89

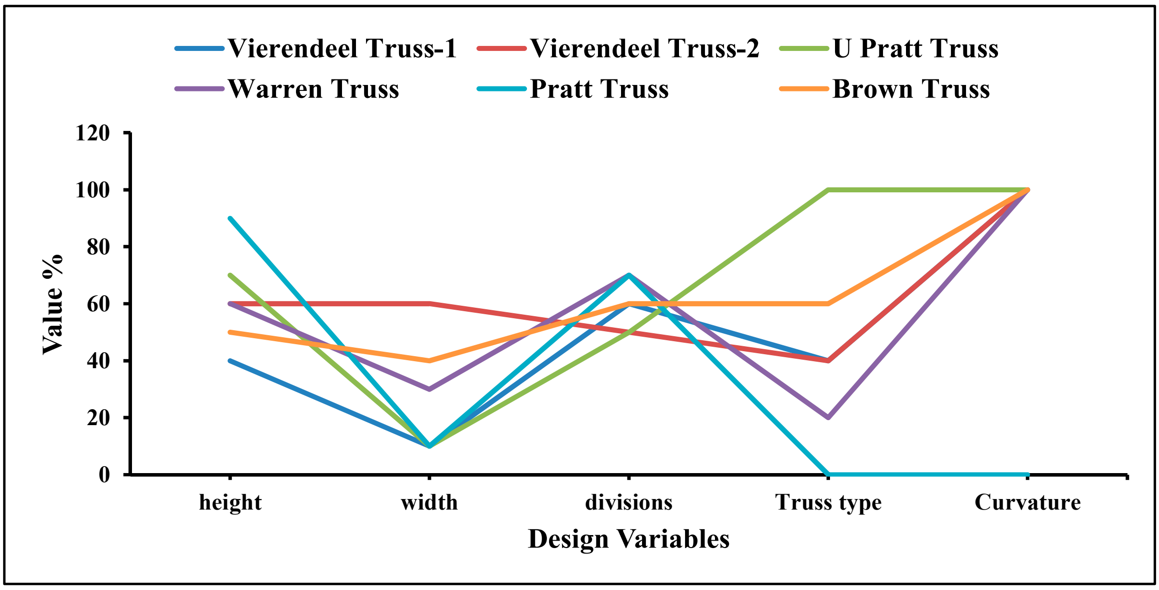


Figure 9. The contribution of design variables among top-performing trusses.

The results of the evolution of the best trusses, as shown in Figure 10, are in accordance with the optimization evolutions found in the literature [34,35].

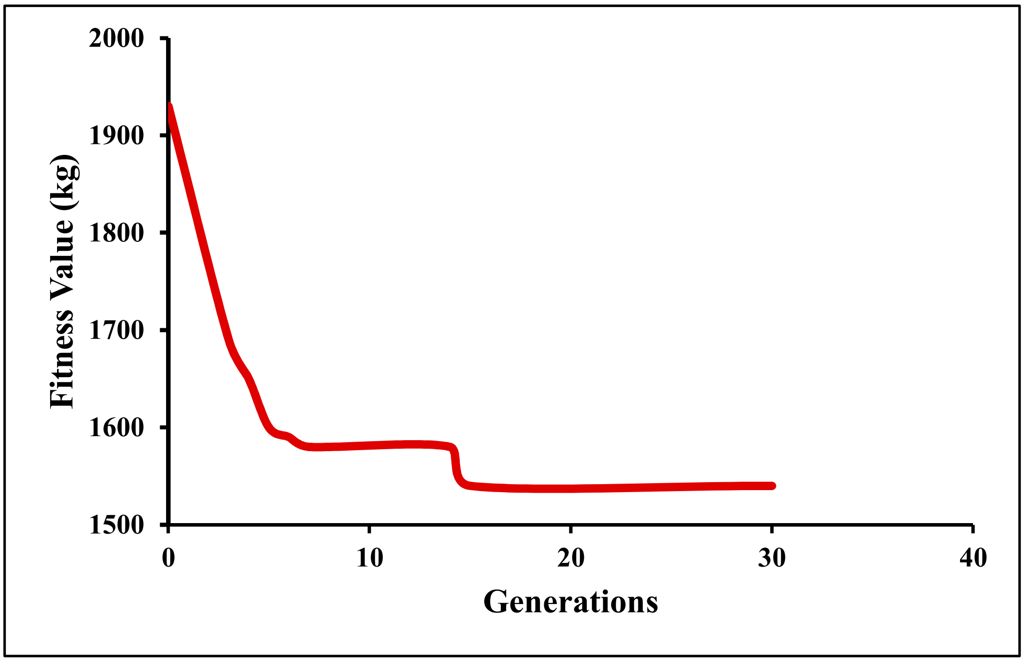


Figure 10. Evolution of the best trusses.

3.7.2. Design of the Finalized Layout for the CPIS

This section offers the analysis results of the CPIS structure from SAP2000. The deflected shape and axial and ending moment diagrams are plotted in Figures 11–15, respectively. The maximum compressive force recorded is 6.5 kips.

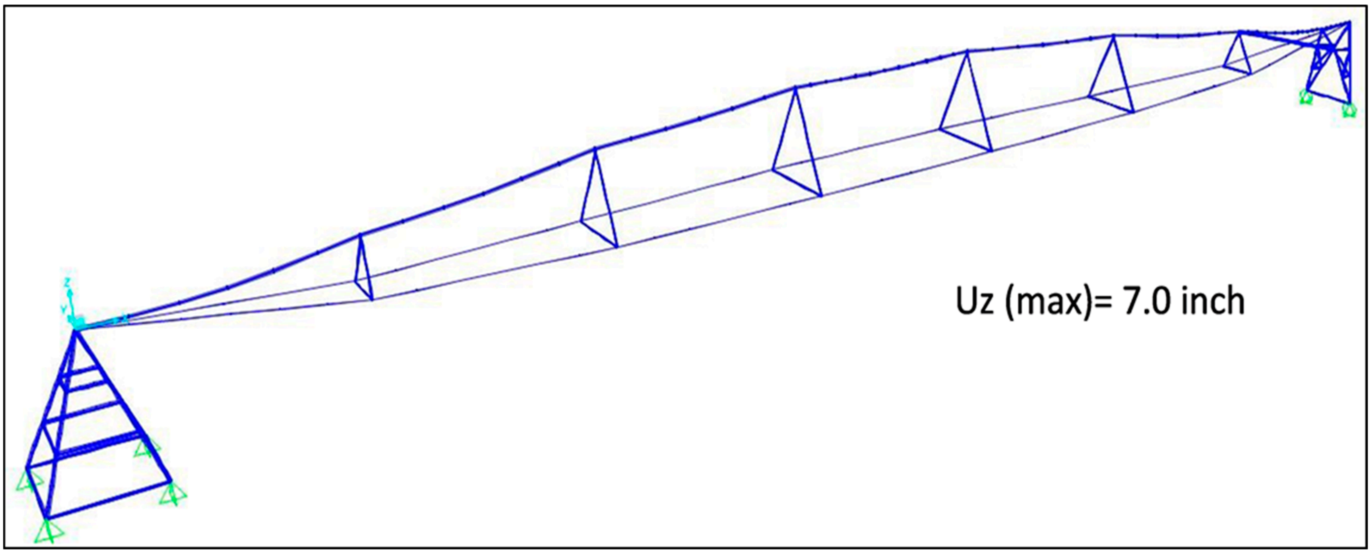


Figure 11. Deflected shape of CPIS structure in SAP2000. Max. deflection recorded is 7 inches.

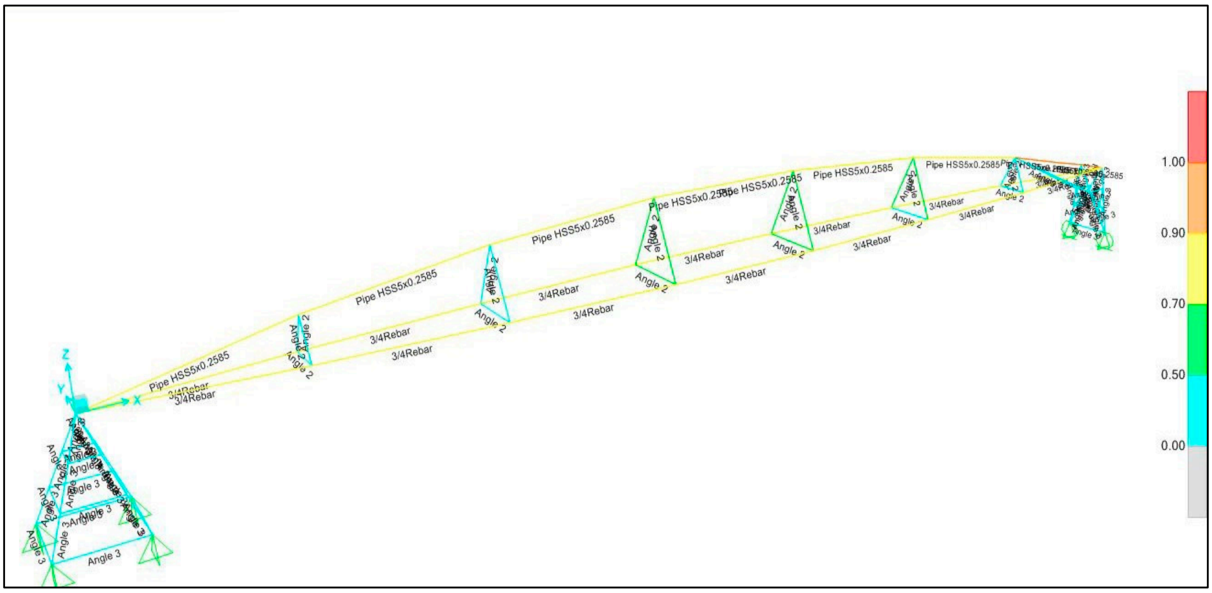


Figure 12. Line diagram of CPIS structure showing frame assignments for different members.

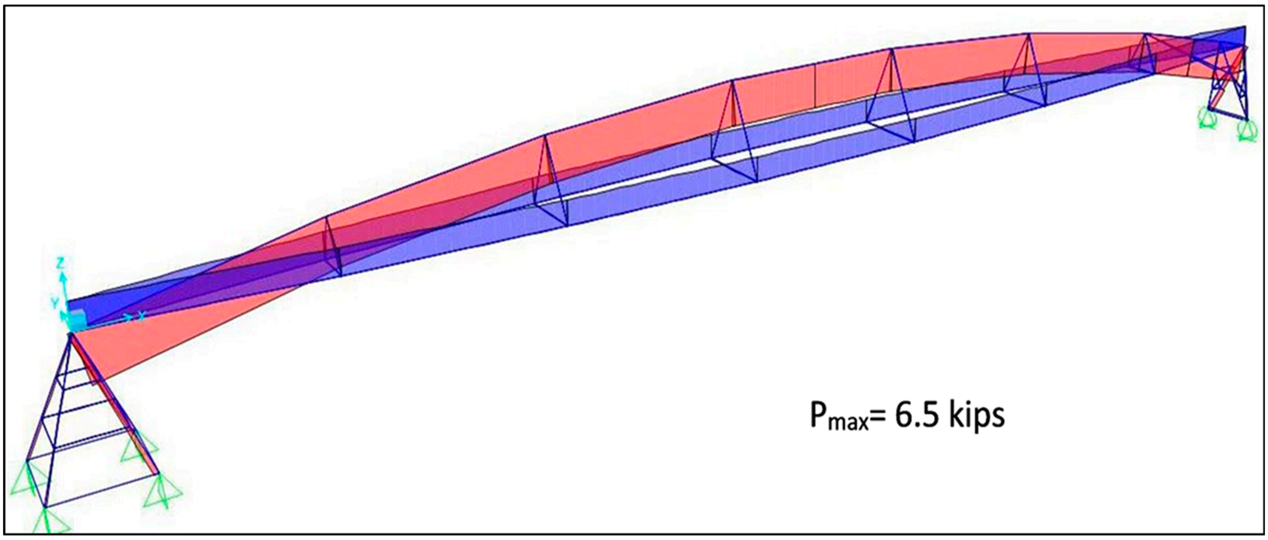


Figure 13. Analysis results showing axial force distribution for different truss elements.

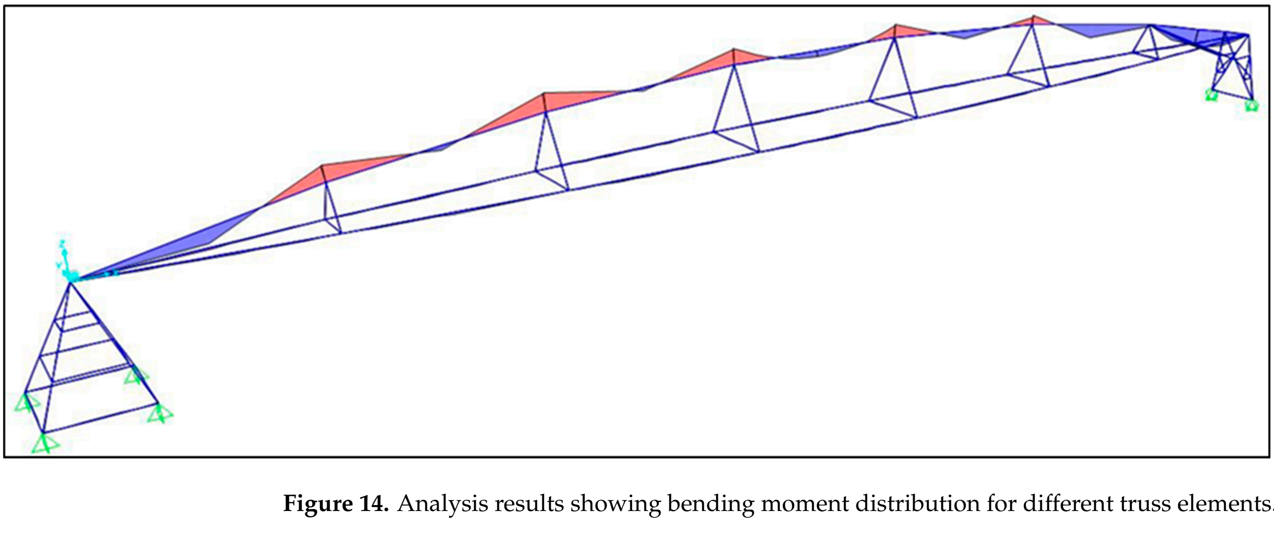


Figure 14. Analysis results showing bending moment distribution for different truss elements.

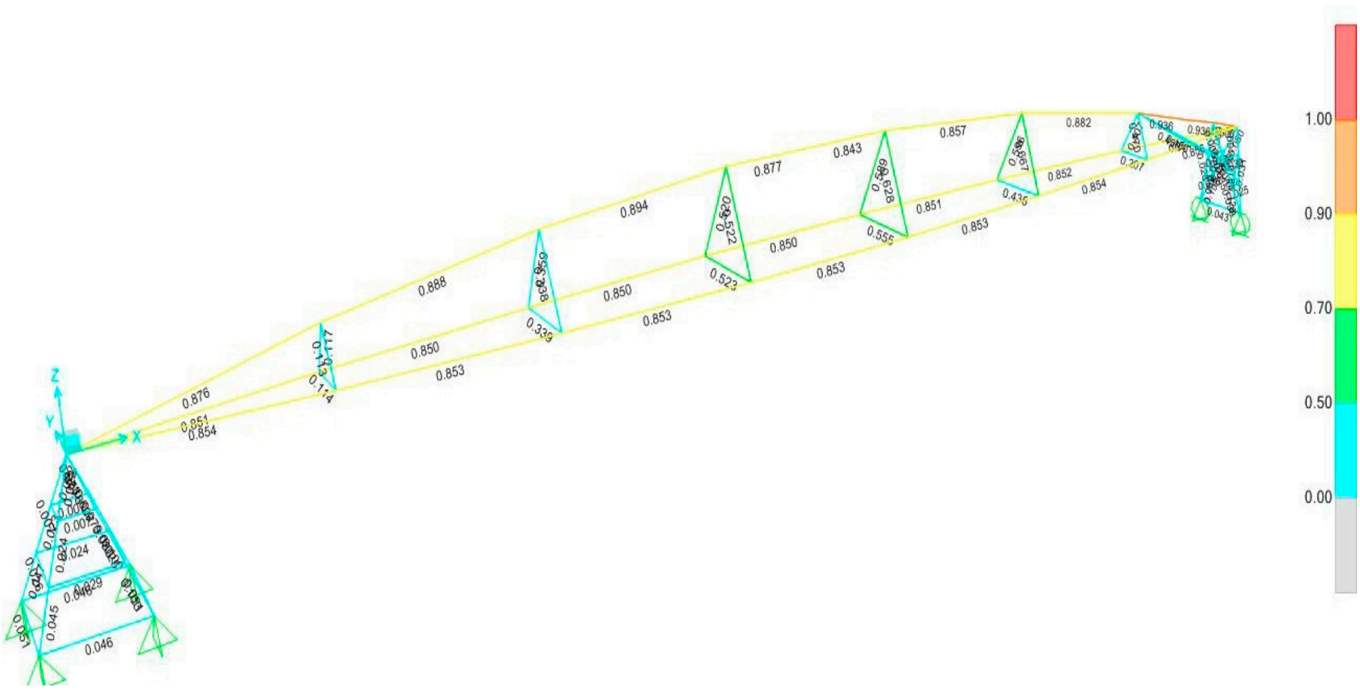


Figure 15. Demand to capacity ratio for different truss elements, as per AISC 360-10 LRFD.

3.7.3. Cost Estimation Results of the CPIS

A large pivot has a low cost, while a small pivot has a higher cost. From a large to a small pivot, as the area of the pivot reduces, the cost increases. However, if the technology is imported, the cost per acre is expensive, while it is low locally. The costs per acre, for both local and imported technology, decrease as the expanded area increases from small to large. Figure 16 illustrates the declining trend of costs for both imported and local estimates.

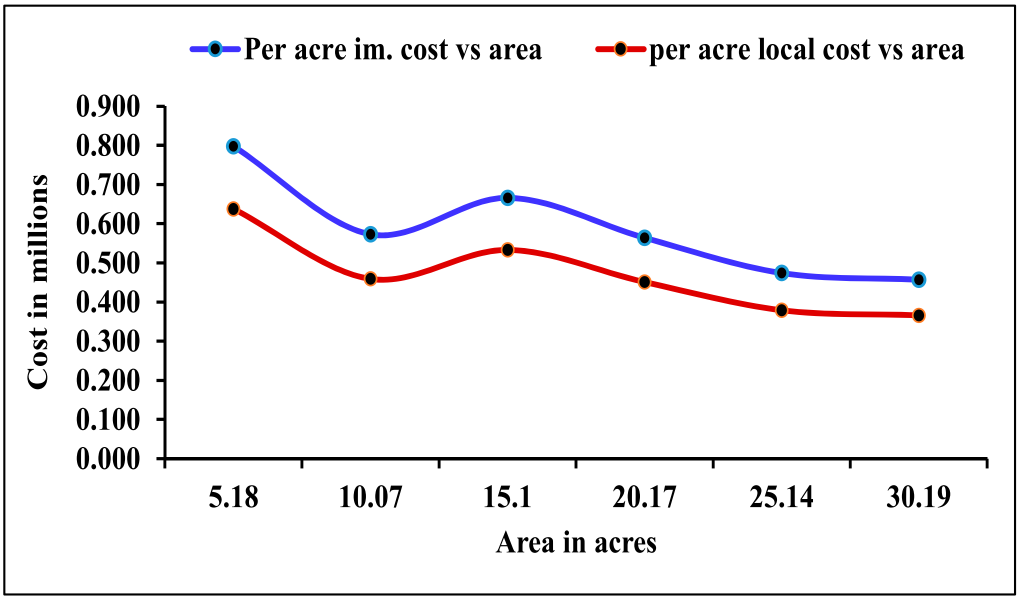


Figure 16. Comparison of imported and local costs of a CPIS.

For the system design for 5 acres, the imported cost is INR 0.8 million, and the local cost for 5 acres is almost INR 0.65 million. When the area increases from 5 acres to 30 acres, both the imported and local cost decrease from INR 0.5 million to INR 0.4 million. In Pakistan, the land holding capacity is small, and small-scale farmers cannot bear this huge cost. Therefore, a towable center-pivot irrigation system is an alternative for small-scale farmers, as it can be moved from one location to another, and the water covers a larger area with a single system. It becomes practical when it is purchased by two or more farmers (Figure 17).

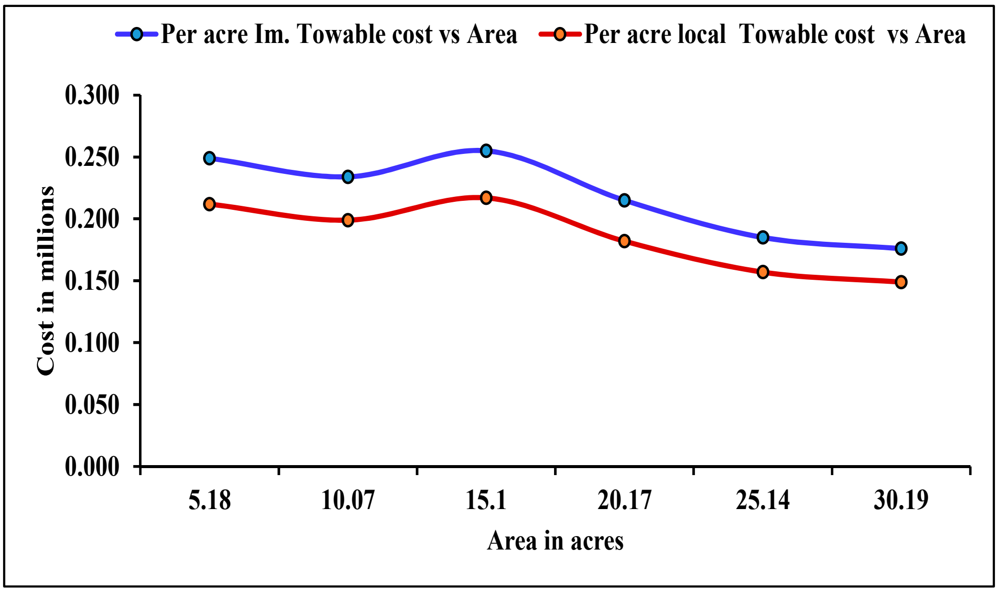


Figure 17. Comparison of imported and local costs of towable CPISs.

Figure 18 indicates the imported and local costs of a towable pivot from 5 acres to 30 acres. For a five-acre area, the imported cost of towable is INR 0.25 million per acre, whereas the local cost is INR 0.21 million per acre. The difference between the system's imported and local towable pivot costs is negligible. The first and second curves indicate the fixed center-pivot's costs per acre, both locally and imported, for areas ranging from five to thirty acres. The trend of cost per acre lowering is evident in both graphs. The imported and local costs of the towable center-pivot per acre for 5 to 30 acres are shown in the third and fourth curves. These costs are lower than those of fixed center-pivots for small-scale farmers. Figure 18 indicates a declining trend for both imported and local towable costs, as well as imported and local system costs.

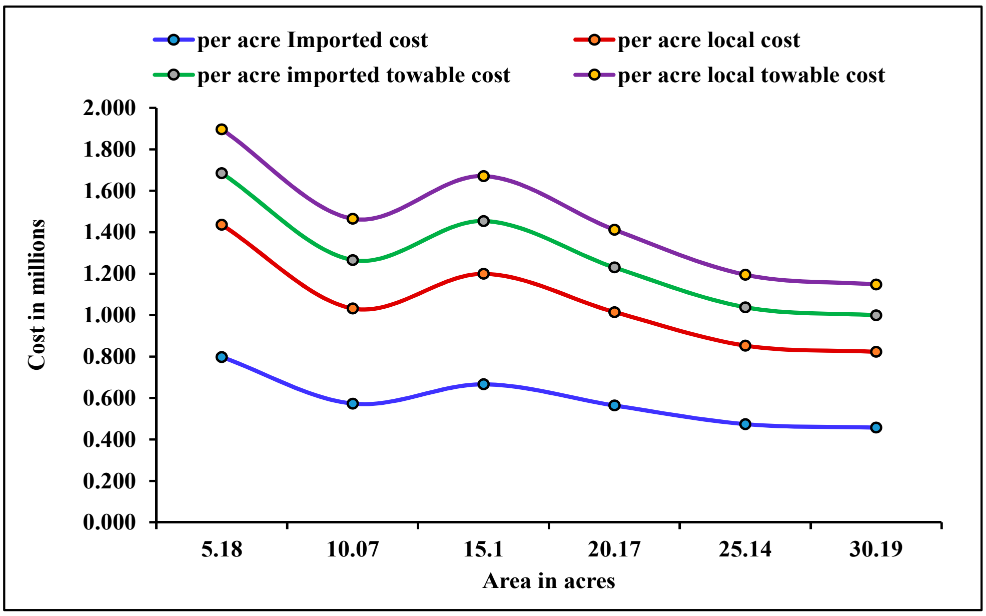


Figure 18. Comparison of imported and local costs of CPISs per acre.

To decide which CPIS design is most economical for both large and small areas, a 250-acre area is recommended for the center-pivot [42,43]. After that, CPIS maintenance will cease when the field area increases by more than 250 acres. As hydraulic pressure and energy consumption increase, an enormous amount of horsepower is needed to run the whole system. Leaching will increase and the soil's nitrogen content will decrease due to the change in nozzle discharge and certain leakage issues [44]. Figure 19 depicts the cost estimation from small to large sizes.

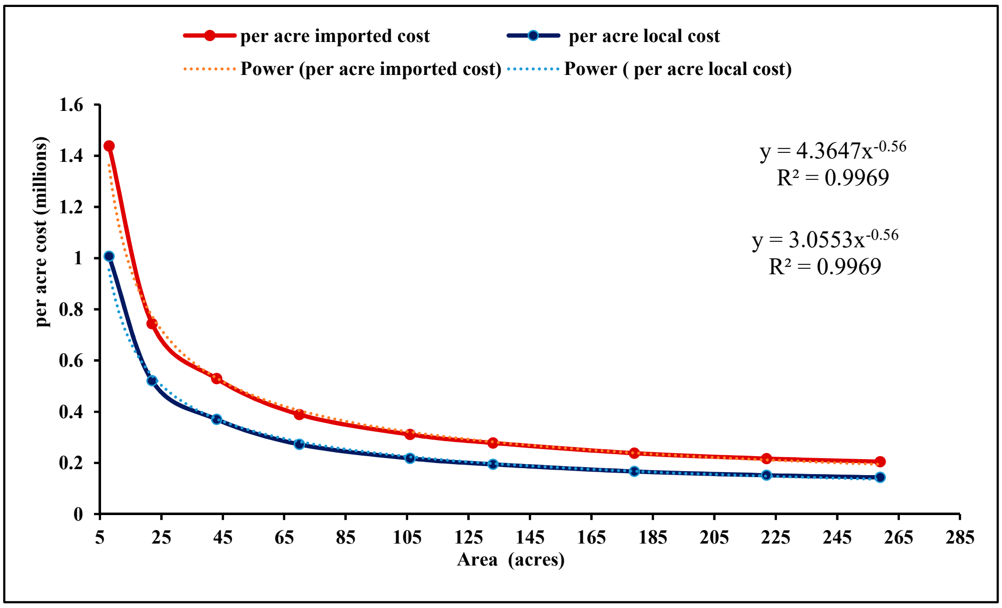


Figure 19. Per acre imported and local cost trends.

As previously stated in regard to the cost estimation findings, as the area increases, the cost per acre of the CPIS is reduced. The CPIS cost per acre does not significantly alter if the area increases by more than 250 acres. When the area is extended from one acre to five acres, the cost per acre is reduced by 59%, but when the area is extended from 250 acres to 270 acres, the cost increases by 1%. Consequently, the CPIS is not intended for areas larger than 250 acres. The trend of decline per acre cost is shown in Figure 20.

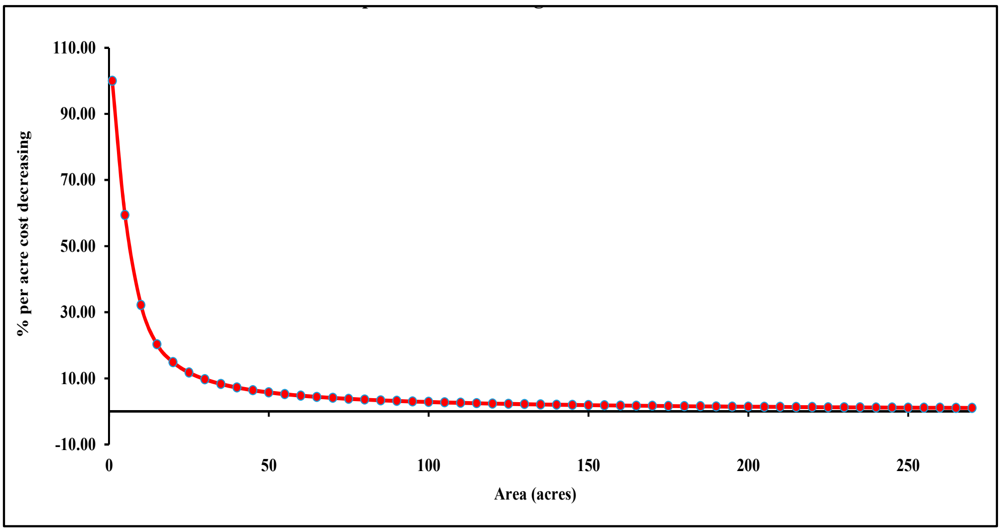


Figure 20. Percent per acre cost decreasing trend.

This study highlights the drastic issue in Pakistan's agricultural sector, where the supply of surface water for irrigation is dwindling as the demand for water in agriculture continues to rise. To address this challenge, this study focused on the development and modification of a CPIS tailored to small-scale farmers, with the ultimate goal of improving water use efficiency and crop yields. In regions with an uneven topography, high-efficiency irrigation systems have proven to be effective, with the CPIS representing an advanced form of such systems. However, these systems are typically designed for large land holdings. A need to modify CPISs for small-scale farming is emerging in Pakistan due to the country's growing population and the distribution of land among family members. The most suitable pipe diameter for minimizing water application costs is mostly determined by the irrigated area and, therefore, by the center-pivot lateral pipe's length. It has been determined that dynamic water table level values do not impact the central pivot's diameter. The most appropriate diameters for each size plot are 219 mm (8 5/8 in.) for an area of 30 acres and 168.3 mm (6 5/8 in.) for each design size [45].

The small-scale CPIS is a crucial solution for the economic empowerment of small-scale farmers, as it offers them access to advanced irrigation practices. Moreover, local design and fabrication can significantly reduce the capital cost of these systems, making them more accessible and cost-effective. Valín et al. [23] developed the DEPIVOT model for center-pivot design and to support the evaluation of systems under operation. The model combines several design features, with the main ones including an agronomic design, lateral spans and overhang pipe sizing, as well as the selection of sprinkler packages.

One key aspect of this study is the redesign of the CPIS's structural components, including the mass, geometry, shape and material. The results are promising, with a 17% reduction in weight and a 44% reduction in the joint count, which not only reduces the cost of the system but also enhances its manageability for small-scale farmers. Many researchers used algorithms and modeling approaches for the optimization and reduction in the weight of trusses [46–52].

This research also explores the water application and hydraulic design of the CPIS, emphasizing important factors such as the head losses, power needs, application time for one rotation, lateral length, flow rate and application time. Valiantzas et al. [53] developed analytical expressions to describe the pressure head distribution along multi-diameter center-pivot laterals. Their method can be applied using the Hazen–Williams or Darcy-Weisbach friction loss equations. López et al. [54] developed the CurvePivot 2.0 software for designing CPISs and determining the impact on the increase in irrigation productivity, as well as the reduction in environmental impacts. Baiamonte et al. [55,56] provided a procedure for designing center-pivot irrigation systems to gradually decrease the sprinkler spacing along the pivot lateral and ensure a uniformly distributed water application rate. Musa et al. [57] calculated the uniformity coefficient of a CPIS. Diotto et al. [58] developed a model to calculate the energy encompassed within the materials in irrigation systems and were able to include different characteristics of the project design flow, irrigated area size, pipeline length and the equipment's useful life.

In particular, we discovered that increasing the irrigation depth and number of hours for each revolution was possible when the time setting was decreased from 100% to 10%. This flexibility empowers farmers to tailor the system to their specific crop and soil requirements, ultimately improving water use efficiency. The climate change impact on irrigation system, decreasing yield, less rainfall, and agriculture practices [59–61]. This research provides a valuable cost breakdown of CPIS components. Structural components are identified as the most expensive, accounting for 61% of the total cost. This information is essential for farmers, policymakers and agricultural organizations, enabling them to assess the feasibility and cost-effectiveness of implementing a CPIS on different scales [62–64].

We recommend the use of a towable CPIS for small-scale farmers due to its lower cost per acre. With a cost of INR 0.212 million for 5 acres, this option offers an affordable solution for smaller land holdings, aligning with the broader objective of improving water use efficiency and crop yields for a more extensive range of farmers. Beyond economic considerations, this study highlights the environmental benefits of improved water use efficiency and precise irrigation methods. In regions facing water scarcity, the conservation of water resources is of the utmost importance. Additionally, enhancing crop yields through modern irrigation practices contributes to food security and economic stability, improving the livelihoods of small-scale farmers [65–67].

This study has major implications for Pakistani agriculture. In order to ensure sustainable agricultural practices, new solutions like small-scale CPISs are essential as water supplies grow more limited and land holdings become smaller. By making CPISs accessible and cost-effective for small-scale farmers, the study has the potential to increase agricultural productivity, enhance income generation, and improve food security. In conclusion, this research addresses a critical challenge in Pakistan's agricultural sector by focusing on the design and modification of CPISs for small-scale farmers. The results indicate that this approach is feasible, as well as cost-effective, and holds the potential to significantly enhance water use efficiency and crop yields. Moreover, it serves as an example demonstrating how local innovation can address global agricultural challenges by providing sustainable and economically viable solutions for small-scale farmers, not only in Pakistan but also in other regions facing similar issues.

4. Conclusions

The optimization of a center-pivot irrigation system's design for sustainable water management by small farmers was discussed in this research. The methodology was divided into three parts. First, the CPIC's hydraulic design using IrriExpress software took into account the lateral length, flow rate, sprinkler pressure, flow depth and power needs. Second, we used the SAP2000 software to optimize the structural design of the trusses. Third, we performed a CPIS economic analysis at the local and imported levels in multiple areas.

The findings of this study revealed that the maximum lateral length for 30 acres was 165 m using three spans, and for 5 acres, it was 50 m with one span. A constant sprinkler spacing was used in all the systems, and the number of sprinklers increased from the first to the last span due to the decreasing flow rate. The head losses varied from 22 to 35 m for the optimized designs. In terms of structural optimization, the Variendeel type-II trusses perform better than conventional trusses, and a cost reduction of approximately 32 percent can be obtained. In terms of trusses, the optimization design's weight reduction was achieved by decreasing the number of joints, which affects the economic cost of CPISs. The center-pivot irrigation system is not economically feasible for small land holdings of 5 to 10 acres. The cost per acre for 5 to 30 acres was calculated as INR 0.798 million to INR 0.457 million. However, the cost of the CPIS can be reduced by up to 31 percent if manufactured locally. The towable center-pivot irrigation system is feasible for small land holdings due to its shifting option that reduces the cost per acre.

This study can contribute to the development of a sustainable and cost-effective irrigation infrastructure, supporting both the agricultural sector and the economy. This innovative approach can provide an opportunity for shared resources and expertise, potentially revolutionizing irrigation practices in the agricultural sector. This study only focused on the design of the CPIS and did not include perspectives on fabrication. In the future, research should be carried out on the feasibility of the local manufacture of sprinklers, pressure regulators and hydraulic systems for future reductions in CPIS costs.

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