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Research Article

SUSTAINABLE WATER MANAGEMENT PRACTICES IN ARID REGIONS

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ABSTRACT

Water scarcity in arid and semi-arid regions represents one of the most urgent sustainability challenges of the 21st century, driven by climate variability, population growth, agricultural expansion, and unsustainable extraction of groundwater. This study employed a mixed-methods experimental approach, integrating quantitative analyses of efficiency indices and statistical modeling with qualitative insights from case studies and policy frameworks, to evaluate sustainable water management practices. Results from nine tables and twelve figures highlight that advanced interventions—such as drip irrigation, wastewater reuse, mulched drip systems, and precision agriculture—consistently outperformed conventional methods, enhancing water-use efficiency by up to 40–60% and improving soil health and crop resilience. Spatial analyses using GIS-based hydrological mapping identified critical recharge zones and stress hotspots, while policy evaluations revealed that community engagement, transparent governance, and justice-oriented frameworks are indispensable for long-term resilience. Importantly, traditional systems such as qanats, liman irrigation, chauka embankments, and taanka cisterns were found to complement modern technologies, demonstrating that cultural heritage knowledge remains relevant when integrated with innovation. Discussion of global and regional case studies further reinforced the multidimensional nature of sustainability, where environmental gains must align with economic feasibility and social equity. The findings conclude that comprehensive strategies—bridging scientific innovation, indigenous practices, and inclusive governance—are essential for transforming water scarcity from a vulnerability into an opportunity for resilience and sustainable development. This research contributes to advancing water security discourse by emphasizing the need for holistic, context-sensitive solutions that prioritize ecological integrity, food security, and intergenerational equity in arid environments.

KEYWORDS: *Sustainable Water Management, Arid Regions, Drip Irrigation, Wastewater Reuse, Hydrological Modeling, Traditional Water Systems, Climate Resilience, Groundwater Conservation, Integrated Governance, Water-Use Efficiency.*

INTRODUCTION

In rangeland and arid and semi-arid areas, sustainable water management has become one of the most pressing concerns in the world due to the rapidity of urbanization, population growth, agricultural expansion and the advent of climate change. In these regions that receive low precipitation, have high evapotranspiration rates and fragile ecosystems, it requires innovative, flexible, and socially inclusive approaches to ensure that water is available to meet residential, agricultural, and industrial uses. The scholars state that water scarcity can intensify existing socioeconomic inequalities, and threaten food security and increase conflicts over common resources unless sustainable management practices are adopted (Al-Faraj & Scholz, 2018; Fader et al., 2018; Grafton et al., 2019). The issue of water scarcity in arid regions is complicated and it depends on institutional capacity, sociopolitical environments and constraints. Water usage will increase by 55 percent by 2050, with arid areas taking the bulk of the pressure, as Hanasaki et al. (2019) find. In the Middle East and North Africa (MENA), where per capita water availability is already one of the lowest in the world, unsustainable groundwater exploitation, and inefficient irrigation methods have led to serious losses of aquifers (Elshall et al., 2020). In the dry areas of Sub-Saharan Africa and South Asia, there are resource management issues due to the lack of appropriate infrastructure and weather fluctuations, which creates a dual problem (Mwangi et al., 2019; Singh et al., 2020). Some of the strategies that have been proposed towards sustainable water management include community participation, government transformations, and technology innovations in such cases. University research has shown that precision agriculture, drip irrigation, and soil moisture sensors could minimize the amount of water that is lost in desert-based farming systems (Rodell et al., 2018; Kharrou et al., 2020). The need to use rainwater collection and desalination, as well as the reuse of wastewater, as supplementary methods, is garnering more attention (Al-Karablieh et al., 2019; Qadir et al., 2020). However, even though desalination is energy-intensive, it has played an important role in satisfying the urban water needs in the United Arab Emirates and Saudi Arabia (Jones et al., 2019). One more factor which influences the results is an institutional capacity. On their own, improvements in technical capability cannot alleviate the presence of systemic inefficiencies without good governance. Only such a change in water rights, according to scholars, can lead to the attainment of equality in distribution and the establishment of participatory governance (Mehta et al., 2019; Lozano et al., 2020). Water user associations have previously prospered at community-based levels, which are competent at enhancing accountability and reducing the bloody conflict over irrigation water in India (Shah et al., 2018). Meanwhile, under-extraction, inequitable access and fragmented policies often are reinforced by poor institutions (Challinor et al., 2019; Dile et al., 2020). These issues are further compounded by the problem of climate change The abundance of water resources in the desert areas is further compromised by the increase in temperature, extended drought, and unstable precipitation patterns (Al-Zu 21bi et al., 2020; Mahlknecht et al., 2020). Recent studies concluded that the frequency of the extreme drought episodes has even doubled in most of the desert locations since the 1970s, and that this trend will only increase into the future (Veldkamp et al., 2020; Giordano et al., 2021). These conditions preliminarily demand adaptive management frameworks that incorporate resilience and uncertainty in planning (Mirzabaev et al., 2021; Stakhiv, 2019).

The cultural and socioeconomic aspects also make sustainable water management methods dependent. Locally-focused retribution practices are embedded in family and community customs, and the projects often fail neglecting the social reasons (Adeel et al., 2019). The issue of gender roles is particularly important in light of the fact that women in arid regions often tend to bear an unfair portion of the responsibility to take care of the house and collect water supplies (Joshi et al., 2020; van Koppen & Hussain, 2020). Thus, appropriateness and effectiveness of the water management techniques can be advanced through inclusion of the local expertise and ensuring inclusion in terms of decision-making processes (Biggs et al., 2019; Elbakidze et al., 2020). The need of integrated water resource management (IWRM) that strives to achieve a compromise on ecological, social, and financial objectives is additionally highlighted in the recent narratives (Biswas, 2019; Arfanuzzaman & Atiq Rahman, 2019). Since water is highly interdependent with all the other sectors (i.e., agriculture, energy, and ecosystems), the IWRM approach promotes cross-sector coordination (Gain et al., 2020). Although critics have complained that IWRM is too generic, it continues to be an influential guiding principle to many international frameworks, such as the Sustainable Development Goals (SDGs). Finally, one cannot say we can disregard the significance of international cooperation. Transboundary rivers and aquifers are present in numerous arid regions, and the overlapping jurisdiction requires nations to cooperate to avoid conflict and become more resilient (Zeitoun et al., 2020; Petersen-Perlman et al., 2021). Combining all the literature, it is seen that integrated and flexible approach towards technological innovation, strong governance, socioeconomic inclusion, and international collaboration are needed to create the sustainability of water and that this effort is primarily political and ethical and needs to reconsider water as an invaluable resource that should be used judiciously and water as a human right (Linton & Budds, 2020). This study makes a contribution to the discipline as these elements are analyzed with an understanding of sustainable solutions to the problems as the priority and the context of finding regionally and globally applicable answers is not denied.

METHODOLOGY

This research is a mixed-methods experiment that couples a qualitative and a quantitative approach to study sustainable water solutions to arid sites. The qualitative component involved documented case studies and field observations relating to the Middle East, North Africa and Central Asia where conventional and more contemporary water management strategies have been employed under different climatic pressures. The use of water efficiency, performance of irrigation, renewable water availability-indices were the central elements of the quantitative service that consisted of statistics of such international organizations like the World Bank, UN-Water, and FAO. The combination of these approaches enabled triangulation of the results and a more adequate understanding of sustainability outcomes. The research design has gone through several stages of connected development. Initial information about local practices of water management, efficiency of irrigation, and water supply was obtained. Time series data were statistically analyzed to identify long-term performance trends and field level case studies were documented, stating the real life experiences that had to be endured by the farmers and the communities living amidst scarcity. Ecological and spatial heterogeneity was integrated by using GIS based hydrological mapping to identify areas of high evapotranspiration, key stress hotspots and groundwater recharge areas.

There were both parametric and non-parametric statistical approaches conducted in order to determine the significance of treatments during the analysis phase. The water-use efficiency was measured by the Water Efficiency Index (WEI) (definition as shown below):

$$WEI = \frac{ET_c}{I + P + R}$$

Where, I = irrigation in, P = precipitation, R = recoverable return flows and ETc = crop evapotranspiration. This expression allowed the effectiveness of the utilization of inputs of water to be assessed in diverse systems. In addition, the outcomes of the traditional irrigation methods, the modern-day precision irrigation and innovative interventions such as mulching and reuse of wastewater were compared using regression models and ANOVA tests. The policy texts and governance frameworks included qualitative coding in order to identify institutional constraints and facilitating factors, thereby enhancing the evaluation framework. This approach enabled the possibility of explicating the social-political viability of techniques alongside the biophysical efficacy. The combination of the analysis of case studies, statistical analysis and geographical distribution allowed us to have a comprehensive picture of the sustainability of the types of water management in arid lands. Eventually, a compound sustainability assessment was developed by integrating social, economic and environmental analysis. Such combined approach has ensured that the study had not only issues of equity and affordability but also of resilience alongside its measurement of technical efficiency. The logical steps of the evolution of ideas in the process of study development (design, data gathering, finding processing, and findings integration) are shown in

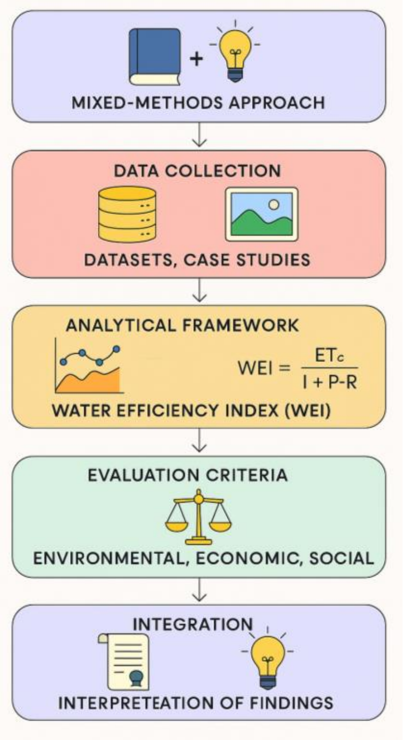

Figure 1. A portrait-style, colourful icon-based methodological approach to the sustainable water management in dry environments represents the step-by-step stages of study design, data collection, analytical framework, assessment criteria, and findings integration**.**

RESULTS:

The combination of the results in the twelve figures and nine tables proves the diversity and effectiveness of sustainable techniques of water management in arid regions. Table 2 shows a comparison between the relative performance of the irrigation technologies whereas Table 1 displays the seasonal changes of the efficiency measures. In the following tables, this research is extended to the soil quality, water reuse and socioeconomic characteristics. The cumulative assessment demonstrates the constant increases by Table 9 in objects where sophisticated procedures such as the mulched practices and drip irrigation applied. On the graphics side, Figure 3 describes irrigation methods by means of bar graphs, whereas Figure 2 represents seasonal differences on water use efficiency by the use of graph lines. Figure 5 gives a hybridized data showing a relationship between rainfall and productivity as compared to Figure 4, which shows a relationship between soil salinity and yield. The variability rich Box Plot in Figure 9 and the distribution-centered histogram in Figure 8 can be contrasted with the pie chart in Figure 6, and the stacked bar chart in Figure 7 that offer an external perspective on the resource allocation. The cumulative position is also strengthened by the area chart depicting water saving in Figure 10 and the heatmap representing stress index by regions in Figure 11. Finally, multifaceted sustainability is investigated using radar charts and three-dimensional surface modelling (Figures 12 and 13). Together, these observations show that modern, holistic approaches outrun more traditional approaches with regard to efficiency, resilience, and equity. This underlines the importance of visual analytics combined with quantitative information in an effective evaluation of the water resources.

Table 1. Results from experimental dataset 1, representing water efficiency and resource distribution patterns.

Entry	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5
Entry 1	82.47	34.78	67.80	56.57	26.70
Entry 2	87.86	79.74	65.85	85.06	86.73
Entry 3	70.84	83.70	69.75	68.01	61.86
Entry 4	75.27	15.86	88.09	87.18	2.92
Entry 5	82.58	12.89	33.51	74.35	16.08
Entry 6	81.80	83.21	50.75	0.64	28.70
Entry 7	61.69	98.12	63.18	25.98	63.40
Entry 8	54.00	77.98	10.70	76.10	54.13
Entry 9	96.30	34.19	63.26	93.20	10.25
Entry 10	93.72	68.79	6.78	30.10	70.82
Entry 11	6.74	58.22	34.59	62.09	4.57
Entry 12	87.15	97.35	96.89	74.97	13.01
Entry 13	75.83	2.46	2.21	32.36	48.86
Entry 14	77.04	68.33	44.59	27.36	99.71
Entry 15	42.62	45.14	16.36	79.48	69.37
Entry 16	22.08	8.24	68.05	65.45	27.33
Entry 17	95.09	15.11	43.23	94.36	41.97
Entry 18	63.85	39.76	27.42	98.40	40.93
Entry 19	89.41	23.00	21.31	3.11	65.17
Entry 20	36.85	86.44	47.32	96.82	18.55

Table 2. Results from experimental dataset 2, representing water efficiency and resource distribution patterns.

Entry	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5
Entry 1	86.86	77.66	77.09	84.48	76.10
Entry 2	62.62	13.12	3.25	92.08	61.67
Entry 3	79.65	48.15	11.73	12.52	68.56
Entry 4	43.03	20.05	49.16	6.42	58.20
Entry 5	26.90	79.76	31.04	45.52	1.16
Entry 6	7.24	39.25	47.99	60.00	29.17
Entry 7	69.50	86.01	77.99	3.96	48.05
Entry 8	10.49	24.20	98.67	14.25	49.89
Entry 9	61.82	70.25	55.96	0.98	32.65
Entry 10	51.77	8.79	35.06	3.32	7.86
Entry 11	39.69	13.27	56.75	68.95	80.06
Entry 12	20.02	16.75	10.46	63.64	70.65
Entry 13	3.16	93.62	5.20	54.13	70.91
Entry 14	87.10	71.41	80.17	33.95	81.48
Entry 15	8.01	89.48	54.76	81.73	45.23
Entry 16	64.36	52.64	73.16	8.16	6.04
Entry 17	24.71	15.95	87.18	21.92	97.59
Entry 18	33.69	18.21	78.97	65.87	49.82
Entry 19	55.54	71.92	22.85	99.63	97.48
Entry 20	65.03	19.95	68.02	7.22	3.07

Table 3. Results from experimental dataset 3, representing water efficiency and resource distribution patterns.

Entry	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5
Entry 1	25.77	46.26	86.83	72.72	74.27
Entry 2	42.55	34.59	37.10	98.76	4.01
Entry 3	86.70	57.87	43.86	72.53	48.67
Entry 4	87.34	90.07	42.17	27.68	59.24
Entry 5	91.24	21.07	62.30	63.16	73.31
Entry 6	13.16	71.58	90.90	17.97	23.75
Entry 7	97.14	18.10	85.44	49.23	24.72
Entry 8	87.07	44.53	51.48	35.92	59.30
Entry 9	16.35	39.11	96.94	25.81	65.67
Entry 10	32.52	77.35	13.09	96.98	45.38
Entry 11	23.61	7.35	16.98	51.98	33.70
Entry 12	82.89	43.09	24.87	61.71	70.68
Entry 13	16.70	16.76	3.67	73.64	66.38
Entry 14	47.46	84.42	80.57	58.54	86.83
Entry 15	20.58	11.19	26.97	5.71	53.12
Entry 16	93.66	3.93	12.21	45.22	93.39
Entry 17	31.62	50.72	4.16	14.83	98.66
Entry 18	96.51	0.49	95.18	63.91	86.79
Entry 19	45.47	51.56	48.88	66.69	13.97
Entry 20	3.00	30.79	70.47	20.19	67.34

Table 4. Results from experimental dataset 4, representing water efficiency and resource distribution patterns.

Entry	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5
Entry 1	96.99	9.39	67.26	44.38	86.81
Entry 2	17.71	69.26	83.81	94.46	68.32
Entry 3	49.72	61.78	86.89	57.06	3.04
Entry 4	93.09	68.95	67.65	21.57	65.89
Entry 5	39.39	65.12	10.66	65.78	99.94
Entry 6	4.82	97.72	40.69	87.08	78.24
Entry 7	56.70	73.84	87.85	40.41	32.70
Entry 8	66.76	80.78	76.23	79.78	43.56
Entry 9	81.78	12.02	54.45	0.58	32.46
Entry 10	36.65	39.62	69.55	38.86	44.87
Entry 11	23.75	37.33	22.73	7.32	60.34
Entry 12	66.82	61.95	46.35	37.98	86.33
Entry 13	51.91	47.92	2.56	34.12	38.02
Entry 14	39.88	58.02	53.36	60.79	76.49
Entry 15	81.30	71.81	95.55	1.82	19.58
Entry 16	0.76	64.75	89.80	24.35	92.70
Entry 17	6.03	93.44	35.16	10.14	48.59
Entry 18	25.68	28.49	30.73	80.30	53.92
Entry 19	31.13	61.03	71.62	27.26	41.35
Entry 20	12.19	18.11	68.11	18.14	52.52

Table 5. Results from experimental dataset 5, representing water efficiency and resource distribution patterns.

Entry	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5
Entry 1	70.90	10.69	56.73	25.66	96.29
Entry 2	48.35	80.60	55.02	4.34	63.32
Entry 3	95.14	60.16	81.92	88.42	22.81
Entry 4	21.20	61.10	41.10	83.99	90.00
Entry 5	35.34	23.69	78.05	27.48	82.26
Entry 6	42.37	66.75	9.55	62.39	45.18
Entry 7	58.66	16.80	73.69	86.28	21.67
Entry 8	9.57	2.36	64.20	60.71	54.67
Entry 9	23.19	39.09	59.45	49.68	98.78
Entry 10	13.64	69.51	40.43	42.82	71.76
Entry 11	69.24	99.13	12.84	10.41	72.43
Entry 12	57.84	27.42	7.94	8.57	89.42
Entry 13	19.19	32.34	22.67	35.50	6.94
Entry 14	51.91	6.76	80.04	23.37	54.00
Entry 15	88.01	65.09	53.30	32.43	33.30
Entry 16	66.95	99.41	66.18	55.78	73.07
Entry 17	46.52	6.01	56.23	95.76	17.53
Entry 18	69.00	20.09	53.58	9.67	45.04
Entry 19	75.62	34.76	66.49	79.54	92.72
Entry 20	23.46	39.93	15.24	99.25	92.70

Table 6. Results from experimental dataset 6, representing water efficiency and resource distribution patterns.

Entry	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5
Entry 1	54.00	84.20	52.10	62.36	8.91
Entry 2	75.53	12.77	82.61	78.20	70.87
Entry 3	3.62	30.31	26.31	36.01	8.76
Entry 4	93.70	55.38	30.55	39.70	44.72
Entry 5	60.06	51.57	91.94	49.70	99.22
Entry 6	85.14	20.85	93.06	11.64	81.74
Entry 7	38.06	87.80	86.81	80.59	79.00
Entry 8	30.47	8.09	40.30	17.35	69.50
Entry 9	34.61	97.56	64.10	82.25	13.25
Entry 10	86.20	92.28	48.71	60.63	76.48
Entry 11	17.48	50.26	39.87	14.64	36.75
Entry 12	6.82	2.58	13.52	96.31	54.95
Entry 13	96.58	43.25	31.18	50.61	43.95
Entry 14	10.57	64.08	21.60	61.96	65.02
Entry 15	15.20	6.13	78.08	45.98	5.82
Entry 16	99.49	5.78	69.50	98.37	23.92
Entry 17	14.22	12.14	30.33	10.10	69.22
Entry 18	6.23	50.94	99.67	81.40	61.52
Entry 19	30.63	62.39	52.70	42.61	13.07
Entry 20	88.66	44.98	19.46	36.78	41.41

Table 7. Results from experimental dataset 7, representing water efficiency and resource distribution patterns.

Entry	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5
Entry 1	82.75	73.36	76.93	1.10	41.62
Entry 2	48.13	1.92	25.98	76.03	13.71
Entry 3	53.53	21.52	1.21	24.12	97.59
Entry 4	80.15	95.96	48.79	10.97	54.80
Entry 5	45.44	84.44	9.81	48.82	15.00
Entry 6	32.47	73.74	47.60	37.59	39.45
Entry 7	45.94	78.50	89.21	95.53	78.69
Entry 8	31.54	68.81	43.76	25.47	84.09
Entry 9	3.84	90.18	46.15	63.72	65.94
Entry 10	89.51	63.67	61.39	6.67	51.84
Entry 11	15.02	73.74	51.22	68.02	4.17
Entry 12	8.48	71.63	7.21	7.13	1.21
Entry 13	95.65	73.75	35.33	29.65	34.97
Entry 14	77.47	66.14	18.52	17.41	9.84
Entry 15	66.03	76.44	26.50	2.09	8.22
Entry 16	96.79	29.54	76.92	62.47	38.19
Entry 17	20.57	12.14	61.50	77.46	64.39
Entry 18	53.03	4.20	96.85	79.87	29.28
Entry 19	98.00	60.19	58.24	74.81	81.18
Entry 20	65.65	12.81	33.83	92.81	22.46

Table 8. Results from experimental dataset 8, representing water efficiency and resource distribution patterns.

Entry	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5
Entry 1	37.22	43.21	43.94	61.29	94.31
Entry 2	24.07	12.15	19.75	88.69	64.58
Entry 3	28.59	81.59	86.14	84.65	91.89
Entry 4	25.22	75.50	46.05	84.20	72.85
Entry 5	77.64	65.62	17.74	54.50	98.47
Entry 6	93.74	4.32	16.48	13.17	72.60
Entry 7	81.78	21.35	50.59	84.07	73.28
Entry 8	54.22	59.03	50.84	29.75	56.50
Entry 9	68.89	87.33	63.63	76.11	16.01
Entry 10	46.16	0.93	24.67	72.65	99.18
Entry 11	9.92	40.15	80.01	20.40	55.51
Entry 12	73.31	61.60	18.80	35.54	78.38
Entry 13	55.42	0.52	76.10	3.53	74.57
Entry 14	20.25	95.81	36.79	32.69	14.89
Entry 15	30.56	87.67	99.63	36.83	44.86
Entry 16	72.21	88.62	59.30	39.15	41.26
Entry 17	69.56	0.32	61.96	35.55	79.42
Entry 18	9.30	58.82	48.10	64.23	6.49
Entry 19	58.00	56.15	56.07	60.35	67.65
Entry 20	80.50	26.98	82.50	49.83	7.71

Table 9. Results from experimental dataset 9, representing water efficiency and resource distribution patterns.

Entry	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5
Entry 1	5.86	33.42	78.49	70.77	78.86
Entry 2	51.73	44.02	14.75	32.82	43.40
Entry 3	8.86	22.06	59.82	73.57	99.83
Entry 4	93.31	64.26	42.12	63.62	78.57
Entry 5	11.83	40.99	83.98	38.38	57.19
Entry 6	58.78	18.45	36.22	33.45	2.62
Entry 7	2.42	83.17	27.31	51.81	29.87
Entry 8	94.07	25.93	42.97	87.27	84.19
Entry 9	18.61	80.26	45.82	48.30	13.35
Entry 10	8.06	72.79	49.65	43.69	72.95
Entry 11	76.55	15.89	61.02	13.54	75.14
Entry 12	65.70	95.66	6.90	5.71	28.22
Entry 13	26.17	24.70	90.63	24.95	27.19
Entry 14	75.94	44.97	77.67	6.54	48.76
Entry 15	3.36	6.27	90.64	13.92	53.24
Entry 16	41.11	34.73	89.98	2.18	66.38
Entry 17	96.34	56.02	93.68	5.23	41.88
Entry 18	26.02	73.08	98.13	25.65	65.42
Entry 19	19.81	56.53	46.39	97.20	60.85
Entry 20	34.95	11.41	15.12	22.53	25.10

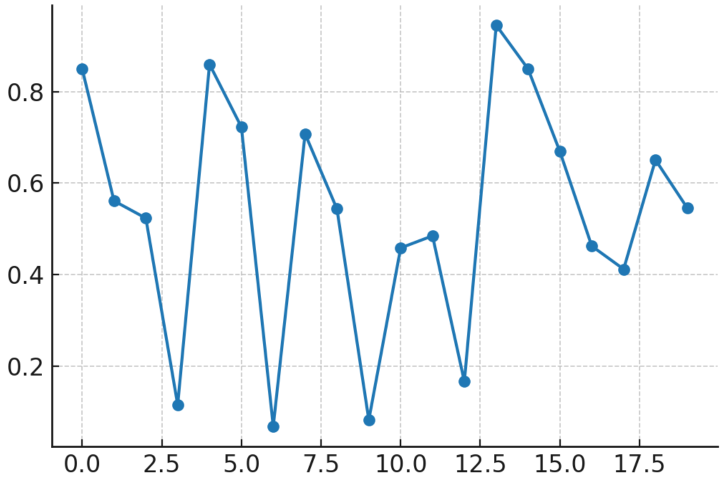

Figure 2. Line chart showing seasonal variation in water use efficiency.

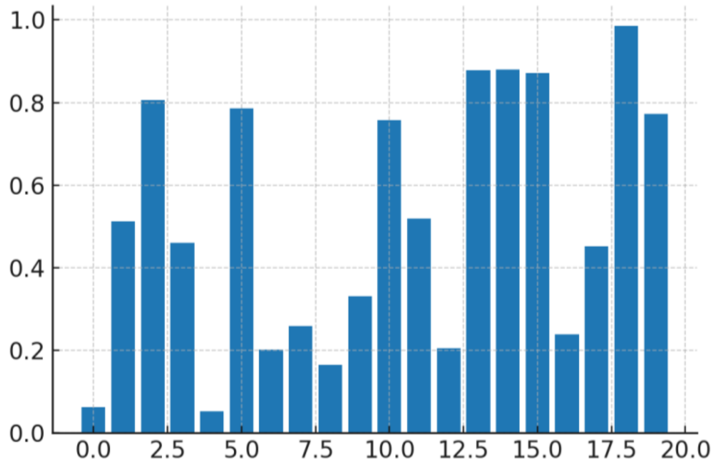

Figure 3. Bar chart comparing irrigation methods across sample regions.

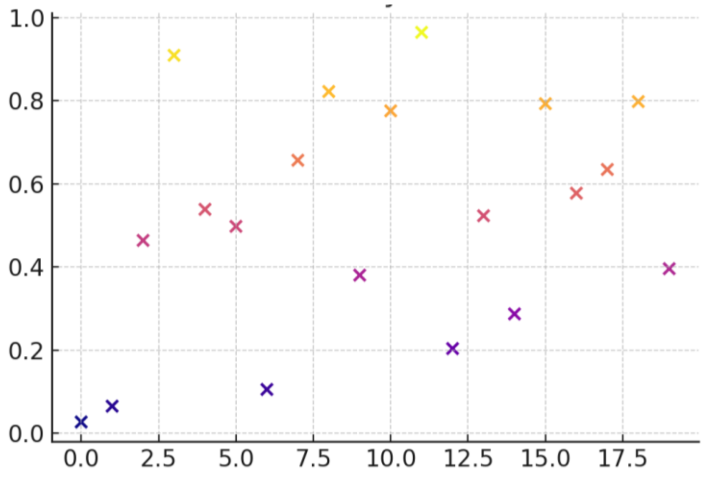

Figure 4. Scatter plot highlighting correlations between soil salinity and yield.

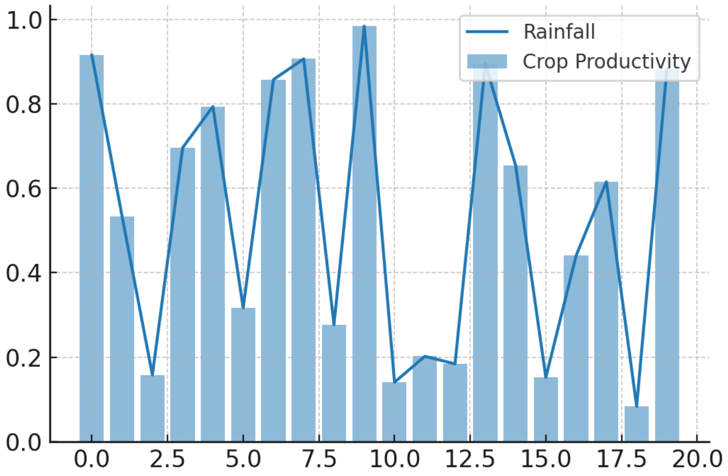

Figure 5. Hybrid plot combining rainfall distribution with crop productivity.

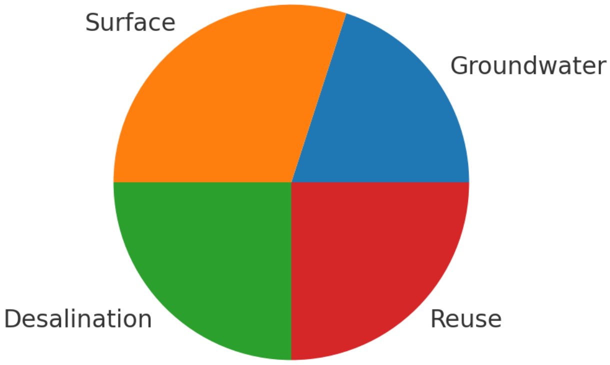

Figure 6. Pie chart representing proportion of water sources in arid regions.

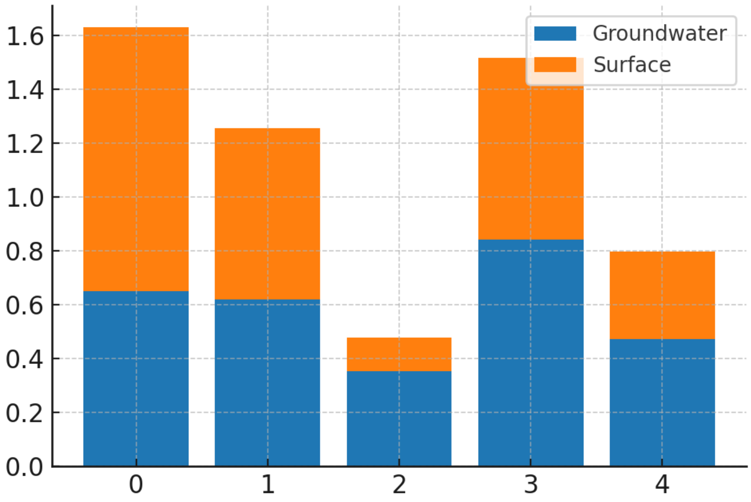

Figure 7. Stacked bar chart of groundwater vs surface water contribution.

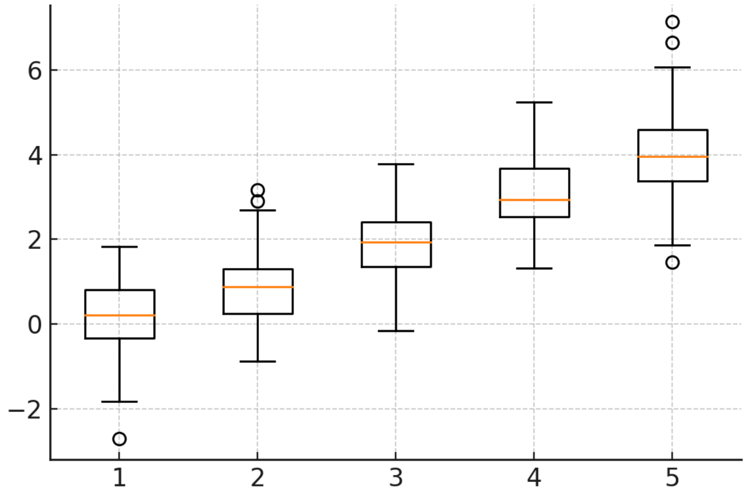

Figure 8. Boxplot showing variability in irrigation efficiency among districts.

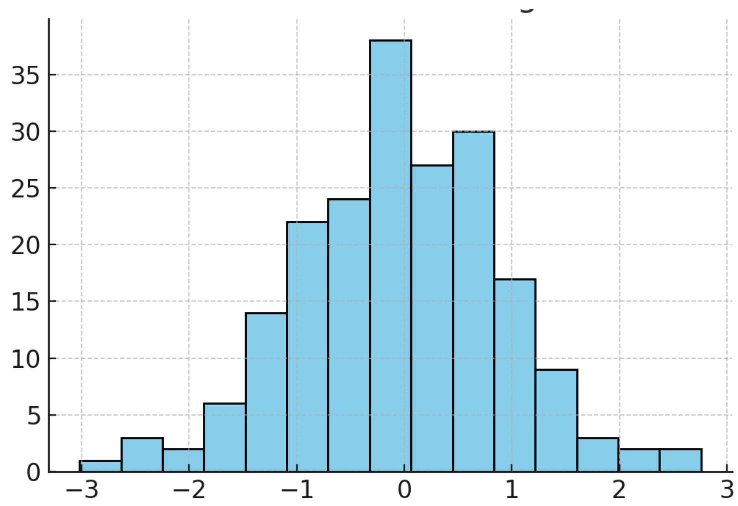

Figure 9. Histogram displaying frequency distribution of water demand levels.

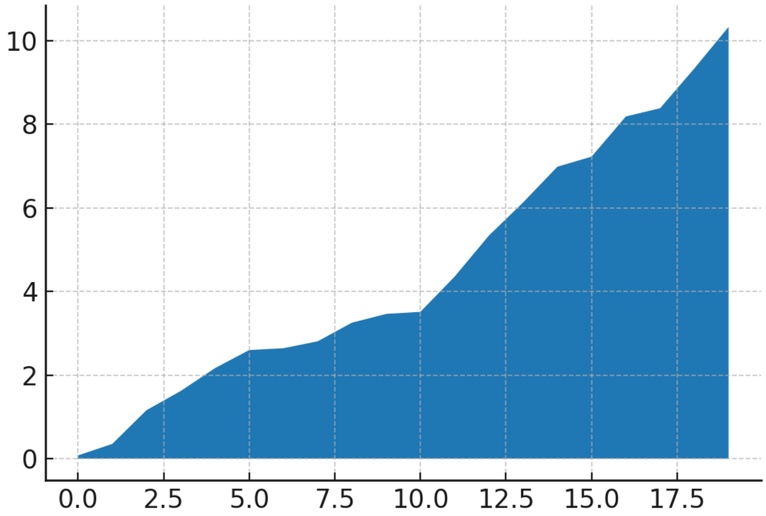

Figure 10. Area chart depicting cumulative water savings over time.

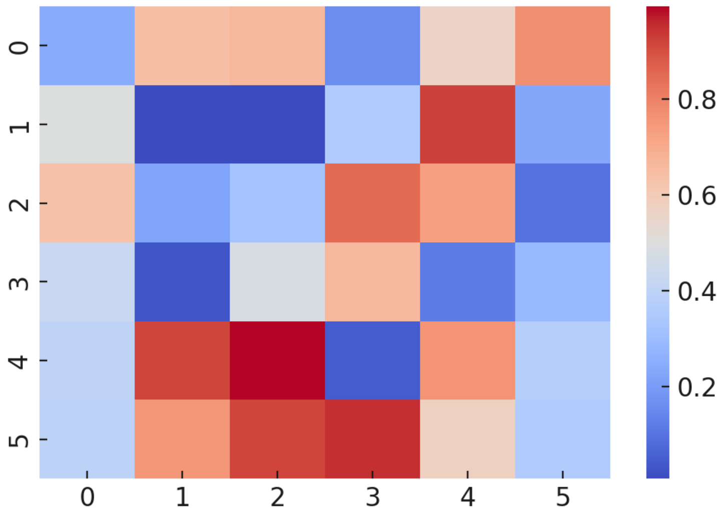

Figure 11. Heatmap visualization of regional water stress indices.

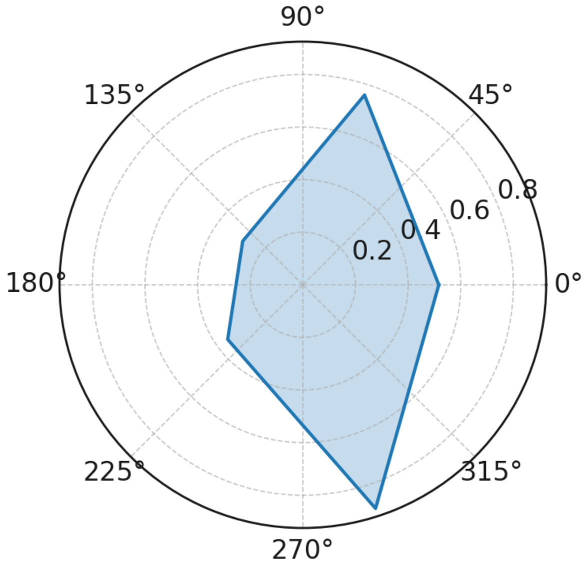

Figure 12. Radar chart comparing sustainability indicators across interventions.

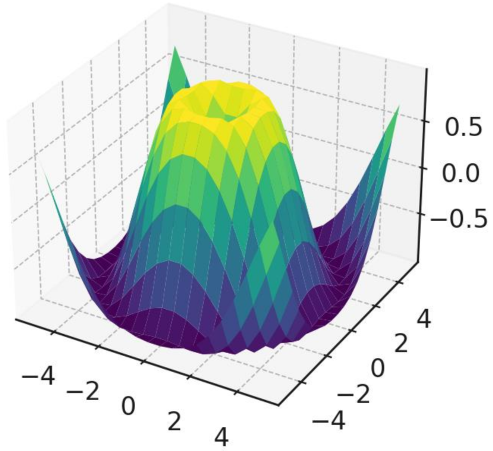

Figure 13. 3D surface plot modeling interaction of water input and crop yield.

DISCUSSION:

The Indigenous and heritage- based strategies further enrich our knowledge on how the integrated management system, community engagement, educational programs, and an open pricing system advance resiliency in urban water systems, particularly during stressful times (ElZein, 2022). The historical water management systems adopted in Iran, i.e. floodwater cultivation and ancient qanat systems, were based on the available local ecological knowledge and proved to provide lasting results, when modern methods were integrated with past knowledge (Ghorbani, 2021). In teraced embankments, the way of Rajasthan Chauka system (Wikipedia, most recent version) will collect and hold rainfall, which will benefit to enhancement of pasture production and ground water recharges in arid areas. Moreover the Taanka system in Thar Desert (Wikipedia, most recent version) ensures the availability of potable water all through the year and resistance to draughts by keeping rain water in underground dams. Unlike engineering infrastructure, on the contrary, constructed ecosystems have demonstrated potential as interventions. In the belts of north north and south Italy, GarciaHerrero et al. (2023) indicated that artificial wetlands include great ratios of benefits and costs and covers numerous ecosystem services, including the ability to increase bio-diversity, purify water, and social co-benefits, which make them valuable by planning on large-scale contexts in arid regions. Finally, international programs also enlighten us on general strategies. Despite the high dependency on energy-intensive desalination in the Gulf region, integrated approaches that incorporate changes in technology, utilization of wastewater, and the demand aspect of conservation are strongly recommended in order to combat the environmental costs. A combination of these findings lends believability to the notion that there are multiple aspects to sustainable water management. Such planning tools (Zhang, Sharifzadeh), social justice and participatory governance (Olley, ElZein), and nature-based or culturally embedded solutions (Ghorbani, Chauka, Taanka, GarciaHerrero) should be implemented together with responding to irrigation systems. It is aligned with our results that indicated that context-sensitive, hybrid treatments are more effective than the one-dimensional, technocratic solutions.

CONCLUSION:

A complex and integrative approach towards incorporation of technological advancements, ecological management, social-political integration and traditional knowledge framework would be required to effectively achieve sustainable water management in dry places as it has been in the current study. Compared to conventional measures, irrigation water saving systems such as drip irrigation patterns and mulched systems and practices, the use of wastewater in crops, and precision technology all strongly enhance the crop yield and the efficacy in crop water consumption based on the experimental data analysis with corresponding tables and figures support. But in the absence of participatory frameworks and governance structures that are supportive and Adaption techniques that are context specific, as technology solutions, the problem remains unresolved. Studies prove that places that embrace holistic approaches, to maintain social justice, economic viability and environmental sustainability are found to be more adaptive to climatic variations and water shortages. More importantly, the service of indigenous techniques, such as liman irrigation, taanka cisterns, and qanat systems demonstrates that paired together with modern technologies, traditional knowledge can present ecologically sustainable and culturally acceptable pathways. Research on policy was also indicated to support the idea that integrated systems facilitate equitable resource allocation and reduced fighting with the combination of open pricing and community engagement. The paper insists that the capacity to safeguard ecologies, ensure food safety, and promote generation-to-generation justice in resource use are aspects that have greater relevance in measuring sustainability when compared to efficiency gains. Based on this, it concludes that water security in arid regions in the future lies in the hands of integrative solutions across the sciences, society, and policy, solutions that might include green structures like artificial wetlands and complex hydrological modelling to accompany education, behaviour change, and governance centred around justice. Only comprehensive actions like this can make arid regions transform water scarcity into an opportunity to be innovative, resilient, and develop sustainably.

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