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Estimating the Water Poverty in Semi-Arid districts of Punjab, Pakistan

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ABSTRACT

An increase in population and water demand, climate change, and changes in land-use patterns are severe problems in Pakistan. Water management in Pakistan has been a provincial matter after the 18th amendment. Each province in Pakistan measures the water on its own intention and indicators. The current study aims to map the water scarcity status through the water poverty index (WPI) using the Multiple Indiactor Cluster Survey (2018) at the semi-arid districts in Punjab, Pakistan. WPI was estimated by using the components named "Resources," "Access", "Capacity", "Use", and "Environment". Each component score was calculated using ifferent indicators, assuming equal weights for all components. Layyah (57.6) and RajanPur (48.03) had the best and worst situations among all districts in 2018. The findings showed that the absence of physical water resources in these districts is not the only factor of domestic water shortage but environment and capacity also plays a significant role in achieving the domestic water need. Due to their socioeconomic ineptitude, lack of infrastructure, and restricted access to water, the region is experiencing severe to high levels of household water poverty. This study's results showed that WPI is an operative tool to measure water scarcity and could be used to make an important priority for water management.

Introduction

Water is one of the most important resources for human life on earth (Westall & Brack, 2018). It participates in a range of biological and environmental processes (Hintz & Relyea, 2019; Xia et al., 2021), emphasizing human welfare and health (Vogeler et al., 2022). However, climate change, economic development, trade, and population increase have endangered this vital resource in terms of quality and quantity (Edamo et al., 2022; Jemmali & Sullivan, 2021). It is currently acknowledged as one of the most swiftly disappearing resources and contaminated (Akhtar et al., 2021; Hairom et al., 2021). Governments and policymakers are increasingly concerned with providing all families with clean and sufficient water, especially in emerging nations (Hailu et al., 2022; Moe & Rheingans, 2006; Sobsey et al., 2008).

The crucial aspect of overall water scarcity that has the greatest impact on people is domestic water scarcity (DWS), or the lack of safe and sufficient water for household needs (Crouch et al., 2021; Strauch et al., 2021). According to several research studies, the absence of sufficient and clean water for various uses led to a total human quality of life reduction by restricting diverse wellness and escalating health issues (Shrestha et al., 2018; Sudsandee et al., 2022). However, a third of the world's population still lacks access to enough clean drinking water, and almost 4.2 billion people still live without access to secure, sanitary facilities (UNICEF, 2019). Hence, it is essential to assess and physically pinpoint the water shortage condition to address the discrepancy in household water availability. Particularly in the semi-arid regions of emerging nations, where complicated socio-economic circumstances have made the natural shortage much more severe due to population diversity.

The commonly employed water planning and evaluation methods are primarily centered on just one aspect of physical availability (Gain et al., 2016; Kummu et al., 2010; Octavianti & Staddon, 2021), neglecting the reality that economic, social, and environmental aspects are directly correlated (Sullivan, 2002; Zeitoun, 2011). Nonetheless, other studies contend that the real water shortage goes beyond the actual scarcity of water (Garriga & Foguet, 2010; Jafari Shalamzari & Zhang, 2018; Jemmali & Sullivan, 2021; Lawrence et al., 2002; Sullivan, 2002; Veettil & Mishra, 2018) and estimates this actual water scarcity. From a social and economic point of view, we need to pay special attention to how water resources are used and managed. In other words, since a community's actual water shortage is multidimensional, it must be investigated using a set of aggregate indices that include information from several fields (Hughes, 2022; Molle & Mollinga, 2003; Sullivan, 2011).

The water poverty index (WPI), which is capable of comprehensively expressing the complex nature of water concerns, was initially presented by (Sullivan, 2002). additionally, as highlighted by (Lawrence et al., 2002; Sullivan et al., 2003), this WPI index provides a single numerical number that anybody may use to assess, track, and communicate water shortage across various locations (Jemmali & Matoussi, 2013; Jemmali & Sullivan, 2021).

As was discussed in the preceding section, maintaining the physical presence of sufficient water supplies is not the appropriate approach to resource management. It has been previously documented that several anthropogenic elements, such as poor income and other social problems, including class, caste, societal power relations, etc., may put restrictions on access to water (Edwards et al., 2005; Jemmali & Matoussi, 2013; Ladi et al., 2021; Lawrence et al., 2002; Sullivan, 2002; Sullivan, 2011; Sullivan et al., 2003; Veettil & Mishra, 2018). As a result, multidisciplinary indicators are useful in guiding decision-makers through planning and prioritizing water management (Hamed, 2022; Ladi et al., 2021; Pandey et al., 2022). The Water Poverty Index (WPI) links household well-being to water availability and shows how much water scarcity impacts human populations locally and globally (Tazkiyah et al., 2022). As previously indicated, the WPI contains five components because it is a multidisciplinary measure. The resource component assesses the availability of water resources, 2) the access component, which specifies how a community can obtain water resources 3) a group of factors that influence the society's ability to function economically and socially is referred to as the capacity component. Here, the emphasis has been placed on metrics that show the community's water management capacities, 4) the Use component, which evaluates the real amount of water consumed, and 5) the environment component, which includes several indicators that had an impact on the water quality.

Additionally, it assesses how various environmental factors affect water quality. Moreover, each component contains several constituent parts, and the choice of indicators is context-based (Jaren & Mondal, 2021; Prince et al., 2021). For instance, variables that indicate water shortage should be considered in WPI analysis to quantify domestic water scarcity from a multidimensional viewpoint.

Semi-Arid districts consist of Bhakkar, Mian-wali, Dera Ghazi Khan, Rajanpur, Layyah, and Muzaffargarh. Water shortage became an increasingly pressing problem in these districts, mostly due to the prolonged and sweltering summer and its geological origin (Ahmad, 2011; Jamil, 2019; Khoso et al., 2015). Semi-arid regions are mostly formed by the Desert, whereas dry areas are created by the granite-gneiss formation, which has a low capacity to hold water (Abu-Allaban et al., 2015; Jabeen et al., 2022). Additionally, the semi-arid district's geography is distinguished by rough and sloppy terrain due to its plateau position, which reduces the monsoonal recharge by raising the likelihood of runoff. In addition, a wide range of human activities substantially influences these districts' access to household water (Hayder et al., 2022). For instance, the district's water resources, which provide the majority of the water for domestic use, quickly dry up. Furthermore, water shortage in these districts may be caused by poor economic standing and a lack of surface and groundwater infrastructure. As Mahmood et al. (2020) reported, these districts are among Pakistan's most economically and socially underdeveloped.

In light of the context mentioned above and taking into account the significance of water scarcity for human welfare and health, the current article attempts to evaluate the domestic water scarcity condition in the Semi-Arid districts of Punjab from a multidimensional aspect. The following are the specific objective of the current paper: adopting a better multi-disciplinary composite measure to evaluate the semi-arid Punjab district's multifaceted domestic water shortage. To assess each sub-composite index's level (component) impact in determining a region's domestic water poverty status.

The WPI has limitations even though it is one of the methods frequently employed for the multidimensional assessment of water availability (Chopra & Ramachandran, 2021; Hussain et al., 2022; Komnenic et al., 2009; Sullivan et al., 2006). For instance, in their study, Octavianti and Staddon (2021)

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highlighted that the primary issues with the WPI are the weights and aggregation. Korc and Ford (2013) questioned using equal or subjective weights for each component since it leads to biases. As per Molle and Mollinga (2003), the impacts were neutralized by the simple aggregate of elements, which eventually impacted the usability and applicability of WPI. But it is also discovered that the WPI findings can be enhanced by using an appropriate correlation-based multivariate approach (Cho et al., 2010; Garriga & Foguet, 2010; Hamed, 2022; Jemmali & Matoussi, 2013; Senna et al., 2019). To boost the validity of the final multidimensional composite index evaluating water scarcity, we have thus refined the WPI in this study using a PCA-based mean weighted technique.

The goals of the current research are to: 1) to assess the each sub-composite index (component) in assessing a districts's domestic water poverty status. 2)Use an improved multi-disciplinary composite index to evaluate the multidimensional household water shortage in semi-arid districts.

The remaining part of this research is organized as follows: in section 2, the data and methodology were discussed. In section 2, the WPI index developed by Sullivan (2002) and Lawrence et al. (2002) are discussed in brief. Section 3 offers results and analysis of each sub-components and WPI aggregation for all semi-arid districts. In section 4 discussed the sub-components and WPI. Lastly, section 5 offers the conclusion and policy implication of this study.

Data and Methodology

This section discusses WPI and the approach used in this research. Multiple Indicator Cluster Survey (MICS) data collected by UNICEF in 2018 were used for constructing WPI.

Water Poverty Index Equation

Since economic, social, quality of water, access, and financial constraints are all significant factors contributing to water endowment, they are not studied in the conventional water scarcity techniques. A few are qualitative; thus, it is difficult to quantify them mathematically. The WPI attempts to combine these elements with the physical aspects of water shortage to present a strong and accurate image of water poverty. WPI tries to answer the social needs of water by “transparency of the process,” by “empowerment of local communities” (Sullivan et al., 2003), and by identifying the indicators determined at the micro level (Sullivan et al., 2006).

Previous studies contend that by organizing the metrics, micro-scale performance may be observed over time and compared to other communities. The WPI is a composite index based on the sub-components expressed as follows:

$$WPI = \frac{\sum_{i=1}^{N} w_i X_i}{\sum_{i=1}^{N} w_i} \quad (1)$$

$$WPI = \theta_R \times Resource + \theta_A \times Access + \theta_C \times Capacity + \theta_U \times Use + \theta_E \times Environment$$

WPI stands for the water poverty index for a certain place, whereas X_i denotes indicator i of the WPI framework and w_i is the weight given to that indicator. Each component consists of several variables, first integrated to produce the components using the same method (Sullivan et al., 2003).

The data used in this research is secondary and combined from various sources. Primary sources are; i) MICS, ii) Meteorological Department iii) Statistical handbook. For example, annual average rainfall data is collected from Pakistan Meteorological Department. The below given table shows the indicators used in this study for each components.

Table 1: Selected indicators for calculating the water poverty index

Symbols	Components	Indicators	Sources
X1	Resource	Resource Variability	Pakistan Metrological Department
X2		Annual Average Rainfall	Pakistan Metrological Department
X3	Access	Access to Water	MICS
X4		Access to Sanitation	MICS
X5		Access to Electricity	MICS
X6	Capacity	Wealth Index	MICS
X7		Unemployment	Statistical Handbook
X8		Illiteracy	Statistical Handbook
X9		Under 5 child mortality	MICS
X10		Child Malnutrition	MICS
X11		Awareness	MICS
X12	Use	Domestic Use	MICS

X13		Agriculture Use	Agricultural Statistical Handbook
X14	Environment	Water Quality	MICS

Data Normalisation

Each variable is normalized using the normalization (Min-Max) approach such that their values lie between 0 and 100. Districts are ranked from lowest to highest according to their values, with district zero having the lowest ranking and district with value 100 ranked highest. The low numbers reveal the district's water scarcity. The normalization method is given below:

$$X = \frac{X_i - X_{min}}{X_{max} - X_{min}} \qquad (2)$$

Results

The results of the empirical investigation of the water poverty index's inter-district discrepancies are shown in this section. As explained earlier, the PCA-based weightage technique has been employed to determine the WPI.

The Water Poverty Index

A water poverty index was estimated at the semi-arid district of Punjab, with WPI scores for these districts in the Table 02 categorized for the overall average. WPI scores deviate from a low of 48.03 to a high of 57.60. Mean values for each component are also given in the Table.

Table 02: Water Poverty Index for Semi-Arid districts of Punjab

District	Resource	Access	Capacity	Use	Environment	WPI
Layyah	25.42	85	49.28	87.29	41	57.6
Muzafargarh	30.5	84.09	44.04	76.45	50.5	57.11
Bhakkar	29.22	86.55	48.97	54.77	45.3	52.96
Dera Ghazi Khan	27.18	67.02	43.55	77.92	36.9	50.51
MianWali	20.79	78.59	50.39	51.48	30.8	48.41
RajanPur	13.57	70.77	39.36	77.03	39.4	48.03

Resources

The estimates attained for water resources at all semi-arid districts in Punjab province are presented in Table. Water resources are distributed into two classifications: Annual average Rainfall and Coefficient of precipitation variation. Resources show the availability of water in every district of Punjab. The results show that the highest shares of resources come from the Precipitation coefficient of variation. In 2018, Rajanpur district had the least range of water resources, having a value of 13.57 for its water availability, trailed by the Mianwali and Layyah, and susceptibility to water scarcity can be increased in these districts. The reliance of these districts on groundwater sources. This reliance, which will result in the exhaustion of groundwater resources and drought incidents, could be treated as the initial warning of water scarcity in Punjab. Regarding water availability, Muzaffargarh (30.50) and Bhakkar (29.22) had the maximum levels.

Access

The above-given table also offers the position of all districts in terms of the “Access” factor. In the access component, this study included “Access to water,” “Access to Sanitation,” and “Access to electricity.” Almost semi-arid districts of Punjab had a high access component except for Dera Ghazi Khan (67.02). The maximum population value with access is 86.55 for district Bhakkar, whereas the lowest value was 67.02 for District Dera Ghazi Khan in 2018. While the district Mian-wali has a value is 78.59 and falls almost in the middle.

Capacity

The water poverty index's third component is capacity, which considers four indicators: wealth index, literacy rate, under-five child mortality rate, and internet access. Concerning education, significant disparities existed among the districts in 2018. Though in 2018, concerning the capacity, Rajan Pur (39.36) district ranked the least among all. In contrast, district Dera Ghazi Khan had the second-lowest value at 43.55, district Mianwali (50.39), and district Rawalpindi (49.28) had the highest values showing greater capacity.

Use

The above-given table offers the statistics attained for the component “USE” of the Water Poverty Index. Concerning domestic water use, despite being an important district, District Bhakkar has the lowest value (54.77). In contrast, Mianwali also has the 2nd lowest value (61.48). District Layyah has the highest value (87.29) for the water use indicator, showing the highest consumption level.

Environment

The value these districts attained on water quality is given in the above table. This "Environment" component was examined based on the intensity of poor water quality. In 2018 nearly all districts were facing poor-quality of water. Nonetheless, it is more deficient in districts Mianwali (30.8), Dera Ghazi Khan (36.9), and Rajan Pur (36.9%).

WPI Aggregation

The values of normalized scores attained for each WPI sub-component and the size of WPI in semi-arid districts are demonstrated in table 01. It is worth mentioning that each component and subcomponents were given equal weights to calculate the WPI. Lawerence et al. (2003) have categorized the WPI as Worse (WPI <48), High (WPI 48-56), Medium (56-62), Medium-low (62-68), and low (WPI >68). As per this grouping, WPI 62 has specified the threshold level. In 2018, the water poverty value for the province of Punjab was 61.35, whereas, in 2018, indicating a medium water scarcity. According to the district-wise results, in 2018, district Layyah (57.60) had the least water poverty among all semi-arid districts. In 2018, the least-performing district was Rajan Pur (48.03), Mianwali (48.41), and Dera Ghazi Khan (50.51). The radar chart of these districts are given in Appendix.

Discussion

This study assessed water scarcity from a different perspective combining physical and socio-economic components. Components such as access, resource, use, capacity, sanitation, and environmental situation have been pooled to represent scarcity better. Taking only the physical availability of water as the components cannot point to water stress. In 2018, district Layyah fell in the low resource district but had a high WPI value. Even though WPI has been widely used in previous studies, it contains the most vital side of water availability (Komnenic et al., 2009).

Access was calculated using three indicators of access to water, sanitation, and electricity (Faraj, 2011; Babel & Wahid, 2009; Sullivan et al., 2006). Our calculations highlighted that almost all districts, 70%, and more population, have access to water except Dera Ghazi Khan (67.02). Though, calculating the "access" by taking only the access to water is not sufficient, as many of the areas of the Dera Ghazi Khan have to spend many days without water when water is transported to these areas by tankers. Whereas long water supply outages can lead to the worsening of water quality when connected. The population's ratio with sanitation facilities for access to sanitation was included. Most districts have sanitation access except a few southern districts of the Punjab province. This low access to sanitation leads to two noteworthy results: the depletion of surface water as the discharge of the untreated sewer, which can decrease the size of the water available. Second is the loss of possible water sources which otherwise could replace the drinking water used for everyday urban and domestic consumption.

One more sub-component that is important for economic development is access to electricity. Regarding electricity, Rajan Pur had the lowest ranking (71.53), whereas the Dera Ghazi Khan had a value of 80.29. These districts had the least value, which can adversely affect the economic situation and management of water. Hamouda et al. (2009) and Komnenic et al. (2009) paid special attention to access to electricity. Hence, improving the electricity facility could be the main concern in the districts mentioned earlier to enhance development and eliminate economic and water poverty.

Concerning the component "Capacity," variation can be seen in all districts. Almost all districts have a more than 65% literacy rate except Dera Ghazi Khan and Rajanpur. Education not only enhances water management but also directly impacts components. Esrey and Habicht (1988) revealed that the mortality rate reduced to 76.2 from 130 deaths if a mother is literate. Van et al. (2010) also examined that illiteracy can increase water scarcity.

Concerning healthcare services, Dera Ghazi Khan had the lowermost ranking among all. This sub-component can directly affect poverty by decreasing infant mortality (Van et al., 2010). In the southern part of the Province, some people usually store water during the summer season. Consequently, this can escalate water-borne diseases and higher infant mortality.

In these semi-arid districts, the value of the wealth index is quite low, except in a few districts. Rajan Pur had a value of 20.28, Muzaffargarh had a value of 22.94, and Bhakar also had a low value (24.94). Increasing the wealth index by increasing income and assets could reduce water poverty. Previous studies also emphasized the increasing wealth index; for example, Hanjra et al. (2009) suggest that the enhanced wealth index could eliminate water poverty. In another study, Renwick and Archibald (1998) discussed that increasing the assets can increase the use of water-efficient technologies and therefore reduce water poverty.

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Concerning the "Environment," the water quality was considered a proxy. As per the calculation, most districts face poor water quality, which can cause a decline in water availability. In the last decade, most districts have faced water quality degradation at a vast level. In 2014, Mianwali had the lowest values, whereas Muzafar Garh had the highest water quality. Akbari et al. (2016) suggested different strategies for managing poor water quality and other water issues comprising drainage improvement.

Conclusion And Policy Implication

In this study, we analyzed water scarcity using the Water Poverty Index in the semi-arid districts of the Punjab Province of Pakistan. An extensive literature review identified the indicators chosen in this study to form the components. The WPI substantiated an appropriate water scarcity method in the Punjab Province of Pakistan, and the final results could be used for policy design. Based on our results, among six semi-arid districts estimated, Layyah (57.60) attained the highest WPI value in 2018. However, the district Layyah faced water variability issues by having a value of 25.42 in terms of the "Resources" component. Enhanced water use efficiency and using the non-traditional method of water sources such as rainwater harvesting for domestic purposes, efficient management of sewage, and improving the component "Capacity" could be a factor to upgrade the water availability not only in district Layyah but also in all other districts of Punjab.

The lowermost position of WPI was attained in Rajanpur (48.03) and Mianwali (48.41) districts in 2018, and these districts should be the top concern of the water policymakers in Punjab, Pakistan. This study suggests that each district must be assessed on its components and not only on the WPI values. Therefore, in these districts, the importance is to enhance the Capacity, Use, and Water Quality component. In Layyah, increasing the better water management can be beneficial to increase the WPI value.

As per our results, the "Water Poverty Index" is most delicate to the "Resources", "Capacity", and "Environment" components. As for the "Environment" component, improved land-use management to control desertification, sewage treatment, and wastewater treatment should be the most important. Moreover, increasing the "Capacity" by providing better education opportunities and income opportunities can expressively increase the WPI. On the other hand, utilizing the water proficiently for better economic growth in Punjab province can expand the "Access" and "Capacity" components and the overall water poverty status.

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