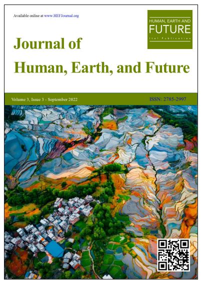
HUMAN, EARTH AND FUTURE
Ital Publication

ISSN: 2785-2997

Available online at www.HEFJournal.org

Journal of
Human, Earth, and Future

Vol. 3, No. 3, September, 2022



Management Options for Large Metropolitans on the Verge of a Water Stress

Muhammad Tayyab [1*], Yasir Abbas [1], Muhammad Waqas Hussain [1]

[1] *National Engineering Services Pakistan (NESPAK), Lahore, Pakistan.*

Received 09 July 2022; Revised 14 August 2022; Accepted 22 August 2022; Published 01 September 2022

Abstract

Karachi is the largest metropolitan area in Pakistan and houses about 14.91 million people (2017 census). It is the industrial hub and financial capital of Pakistan, but unfortunately, it is facing the worst water crisis in its history. Pakistan is bestowed with extensive water resources, but making use of them requires a paradigm shift in water policy and management. Karachi is facing a water crisis situation over the period of three decades, not due to the shortage of natural resources but to mismanagement on the part of the planners and managers, and the situation is getting worse with no imminent solution in sight. The present additional drinking water demand of Karachi has been estimated to be around 650 MGD (260+390) by the Karachi Water & Sewerage Board (KW&SB). This study accesses the water availability in surface water resources, i.e., the Indus River, in consideration of the requisite water demand of Karachi. There exists a mechanism for water transmission from the Indus River to Karachi at the Kotri Barrage. Being located at the tail of Indus, Kotri Barrage (last barrage before outfall into the sea) faces the two extremes in terms of system water availability: in wet season (monsoon), the system happens to be at the mercy of disastrous floods whereas, there is extreme water shortage during the dry months. In this paper, a sustainable water management plan has been devised for managing the additional water needs of Karachi throughout the year. The proposed plan recommends the diversion of additional flows from the Indus River at Kotri (from the water being wasted into the sea), and these flows have been routed through and stored in already existing infrastructure of the KW&SB, i.e., the Kalri Baghar Feeder Upper (KBFU) canal system and Keenjhar, Haleji, and Hadero Lakes. A further scenario-based integrated reservoir operation study presents the optimal use of available flows and storage capacities. In addition, filling and depletion mechanism of available storages has also been proposed and in all the analysed scenarios due consideration has been given to the environmental flows requirement of downstream Kotri riparian and irrigation indents of KBFU system. Hence, the proposed action plan ensures the availability of requisite flows to meet the drinking water needs of Krachi Metropolitan.

Keywords: Water Crisis; Karachi Metropolitan; Water Resources; Indus River; Kotri Barrage; Keenjhar Lake; Reservoir Operations; Water Policy and Management; Environmental Flows.

1. Introduction

Water security is one of the biggest challenges in Pakistan for its sustained development. Providing adequate water for human consumption, agriculture, and industry is a very exigent task for the authorities in the face of ever-increasing water stress, rapidly dwindling water reserves, and the sleeping giant of climate change. Food and water security are the biggest threats to Pakistan's economy. The issue of food and water security in Pakistan is quite tricky, as poorly managed

* Corresponding author: tayyab222@outlook.com

http://dx.doi.org/10. 28991/HEF-2022-03-03-06

water resources and inefficient irrigation practices bear more than 60% losses, and that too with one of the least crop yields per unit of water in the world. Hence, all the pressure happens to be shifting onto already stressed water resources, due to which domestic water availability has been largely suffered. Karachi is the largest, most populous city and economic backbone of Pakistan, serving as a financial (15% contribution to GDP), trading, and industrial hub (housing 60% of the industries). Notwithstanding, the city is suffering the worst water crisis in its history. Foregoing above, the water availability situation in Karachi is expected to get worse if no immediate steps are taken [1-3]. It is very well established that there are certain issues on the management side in addition to the meagreness of available water resources; yet, this paper highlights the water availability potential in the Indus River to mitigate the water stress and proposes management strategies to address the looming water crisis in Karachi.

2. National and Regional Water Profiles

The water availability scenario in Pakistan directly impacts the water available for Karachi, as it is situated at the tail of the Indus River. Hence, nation-wide utilization of water influences the flows being received at Kotri Barrage (last structure on the Indus River). Water availability, sectoral utilization, the history of water supply scheme development in Karachi, and present availability & demand scenarios have been discussed in forthcoming sections.

2.1. National Scenario

Pakistan derives its water resources largely from precipitation and snow/ glaciers melt. Two spells of rainfall are observed i.e., monsoon during summer and, winter rainfalls. The precipitation is distributed quite unevenly both in time and space; almost 60% of the rainfall is received from July- September, and magnitudes vary from less than 100 mm in Sindh and Balochistan to a value of more than 1500 mm in the wet mountains. 92% of the geographic area of Pakistan is classified as semi-arid / arid, and extreme variability in rainfall patterns has direct impacts on river flows [4-6]. Indus being one of the longest rivers in the world is considered to be the backbone of Pakistan as almost all the water sources are derived from Indus basin. The annual flows in the Indus River vary from 92.65 to 207.70 MAF. Another major source of water is groundwater, which has an annual potential of around 55 MAF and of which more than 90% is utilized every year. Figure 1 presents the share of each source and sectoral uses (UNDP Report). Irrigation sector is the largest consumer of water in Pakistan [7-9].

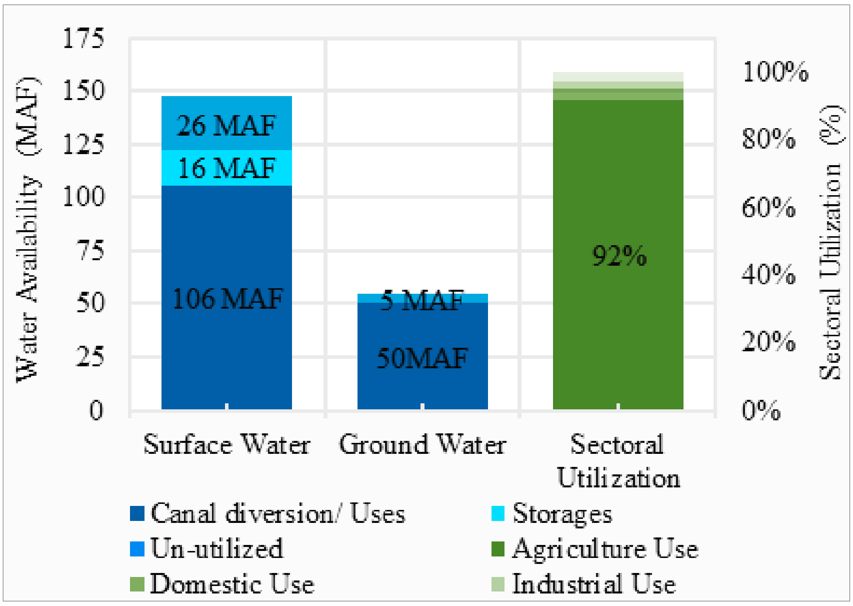


Figure 1. Water Availability and Sectoral Utilization in Pakistan

Over the past few decades, Pakistan's water profile has changed drastically from being a water-abundant country (5260 cubic meters per year in 1950), to one experiencing water stress (under 1000 cubic meters per capita at present) [10-12]. The per capita designed live water storage capacity available in Pakistan is 121 m^3 which is only slightly higher than that of Ethiopia. Pakistan has a storage capacity of mere 30 days whereas, Colorado river in USA stands at 900 days [13]. The water stress levels along with the main causative factor, i.e., population growth, are presented in Figure 2 [14, 15]. Water stress on surface water sources led to rapid groundwater depletion, posing a serious threat to its sustainability, and alarmingly, Pakistan is ranked among the top ten countries having the least access to clean water.

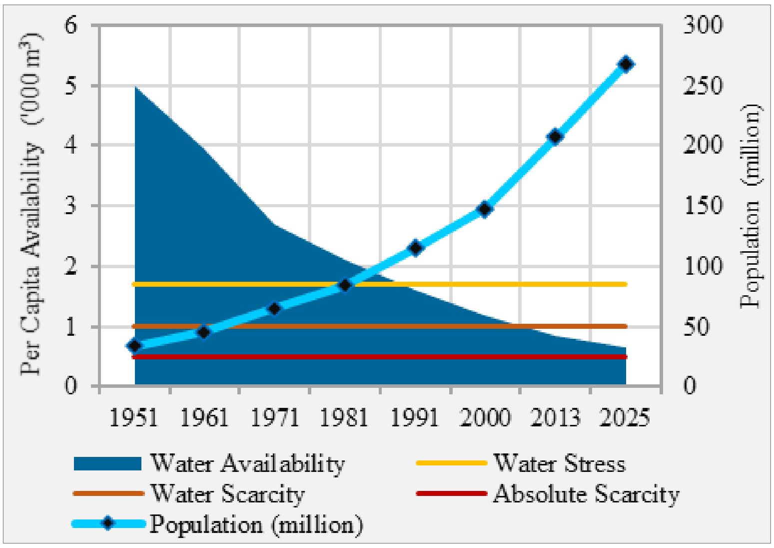


Figure 2. Historic Water Availability and Population Trends in Pakistan

UN Report (2006) findings states *"there is enough water for everyone and water insufficiency is due to mismanagement, corruption, lack of appropriate institutions, bureaucratic inertia and shortage of investment in both human capacity and physical infrastructure"* [16].

Water availability and water security are key issues driving the national security & safety and also have potential in transcending national boundaries as limited water resources results in general destabilization and increased trends of migration. Prioritizing water resources in policy matters at domestic and global levels is becoming indispensable.

2.2. Regional Scenario

Karachi city is located in the south-west of Pakistan and has metropolitan area of about 3,530 km^2. Mlair and Liyari rivers pass through the city whereas, Indus river flows in south-east side where exists infrastructure for supplying water to Karachi via Keenjhar lake which is fed from Kotri barrage through Kalri Baghaar Feeder Upper (KBFU) canal and associated water transmission system. The climate of the city falls under that of specific to arid regions with high temperature (35 to 10 ^{o}C) and small magnitude average annual rainfall (around 85 mm).

2.3. Water Sources and Availability in Karachi

Surface and ground water are the two major sources of water supply in Karachi. Indus river (via KBFU canal and Keenjhar Lake) is the main source along with contributions from Hub dam whereas, ground water sources (Dumlotte wells) contribute in very small percentage because of its poor quality. Some of the water sources development works undertaken over the period of last one and a half centuries are presented in Figure 3 [17-20].

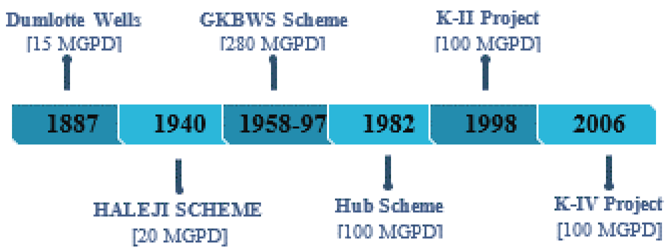


Figure 3. Development of Water Supply Schemes for Karachi

Cumulatively from various sources, at present, authorities mange to provide approximately 665 MGD water against the demand of 1200 MGD, resulting in a shortfall of 535 MGD. Moreover, estimates suggest that 35% of the water is lost in transmission hence, available water drops to a mere 433 MGD [21]. Recent projections suggest that Karachi's population will grow by 30% from year 2017-30 (Euromonitor, London) hence, increased pressure on demand side is imminent.

2.3.1. Water Transmission System from Indus River to Karachi

Water transmission system from Indus to Karachi has been developed since 1940 with the construction of Haleji lake [22]; which was fed from an inundation canal called Baghar canal. Water from Haleji was conveyed to Gharo pumping station via Haleji conduit for onward transmission to Karachi. After completion of Kotri barrage in 1955, the inundation canal was converted to perennial supply. At the same time, provision was made to supply water to Karachi directly from the barrage by taking water from Keenjhar lake through KG canal. Karachi Development Authority (KDA) canal receives water from the KG canal and supply water to Dhabeji pumping station for transmission to Karachi. After commissioning of the Kotri barrage system, use of Haleji lake was not viable, except for an emergency storage. The Line diagram of the system is presented in Figure 4.

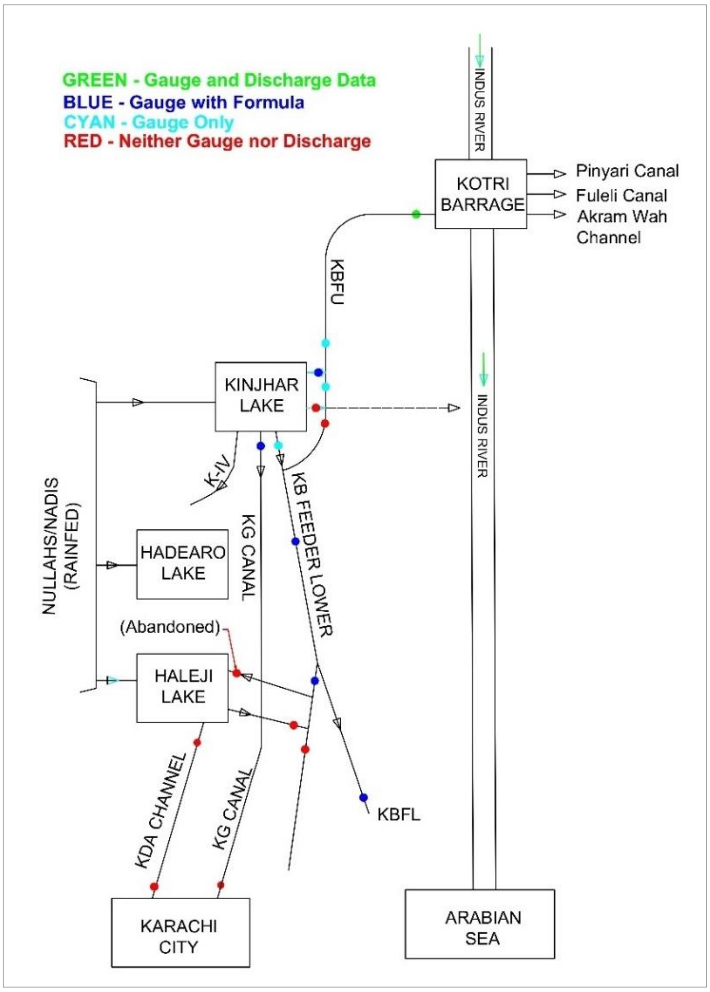


Figure 4. Line Diagram of KBFU and Keenjhar Lake System

2.3.2. Keenjhar Lake Feature

Keenjhar lake had been formed by embanking the eastern side of two lying marshy areas, "dhands", and the remainder of the perimeter being formed by the foothills of Kirthar Range. As per latest bathymetry by NESPAK, the Lake is 32 km long, has surface area of 132 sq. km and live storage capacity of 0.339 MAF at present Maximum Conservation Level (MCL) of 16.45 m asl (54.00 ft) [23]. The intake level of K-IV is planned at 11 m where an additional live storage capacity of 0.119 MAF shall be achieved [24]. Presently, there are two outlet regulators on the lake; the PQ fall regulator (irrigation supplies to Thatta) and KG canal regulator (water supply to Karachi). The lake also receives runoff from catchment area of about 700 square miles. Figure 5 presents the layout of the scheme.

2.3.3. Beyond Urban Water Security: The vulnerabilities of Intermittent Water Supply

Water unavailability is considered to be one of the major factors that handicap the business continuity and economic growth as it poses serious threat to sustainable development and human wellbeing. It has been understood that water availability in Indus River is seasonal and there is very little water available during the winter season, that’s the time when role of storages come into play. Presently, Keenjhar lake is being relied on for meeting domestic water needs of Karachi. Intermittent water supply is the condition under water stress where water is supplied for a fixed period of time that is more costly, exacerbating inequalities among users, weaker people-government social contract and contributes to conflict, violence, or migration. Hence, not only water availability but a consistent supply for domestic usage to Karachi city is indispensable.

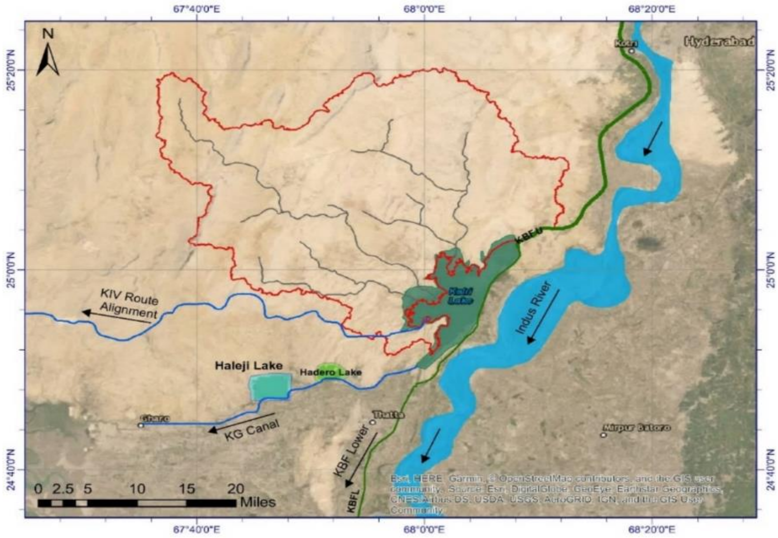


Figure 5. Study Area Features and Scheme Layout

3. Scope of The Paper

The present study has been carried out to: evaluate the potential available at Indus River to meet the escalating water demands of Karachi; to suggest an action plan for meeting additional demands; assess the feasibility of the integration of additional storages into the system; and hydrological modelling in order to ascertain the storage and depletion pattern of the storages.

4. Materials and Methods

Since, the entire project area falls under the command of KBFU canal system, flow data of the entire system (Figure 4) has been collected from Irrigation Department for the last 20 years. Reported gate openings and water levels have been translated into discharge using hydraulic formulae. The major data collection points include (but not limited to): Kotri barrage, KBFU head, -2.4 RD Keenjhar & KBFL regulators, bathymetric survey of Keenjhar, Haleji & Hadero lakes and previous studies on the lake (s). Moreover, climatic data of the study area have also been collected from relevant agencies. A simple but efficient approach has been adopted to check consistency & homogeneity in data, to find abnormalities and correct them before using in further analyses. The entire water transmission system, from Kotri to Karachi, has been analysed for the magnitude and trends of historic flow pattern. System water balance and present operation has been studied at length. Moreover, to manage the additional flows, water availability at Kotri has been analysed, potential in flood spills d/s Kotri (considering environmental flows provisions) to meet the additional demand and operational management of the storages (lakes operations) has also been studied.

4.1. Climatic Indices of the Study Area

Collected daily rainfall (1970 to 2019) and temperature data of Hyderabad show very scarce rainfall around the year i.e. 07 inches on average annual basis and high temperatures round the year. Evaporation data of Pakistan Council of Research in Water Resources (PCRWR) regional office at Drip campus Tando Jam (1996 to 2017) shows average annual evaporation rates of 2,290 mm (90 inch). Climatic trends of the study area presented in Figure 6.

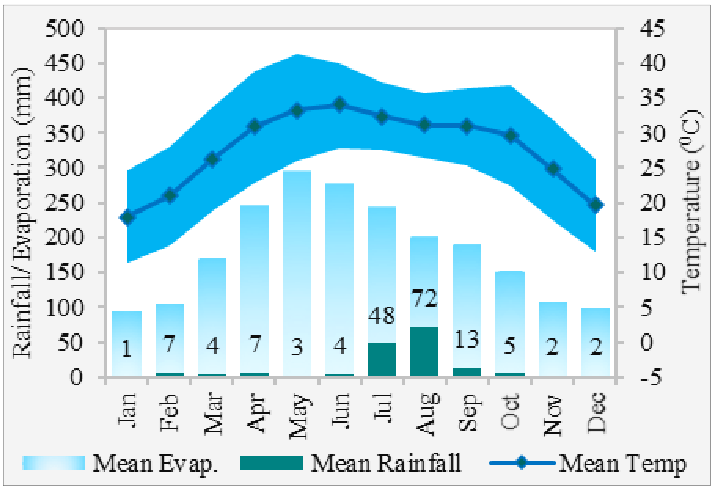


Figure 6. Monthly Rainfall, Temperature and Evaporation Trends in the Study Area

4.2. Water Balance and Operations of Keenjhar Lake

Flow series at key structures have been developed to analyse the historic flows magnitudes & pattern for devising the water management strategy. Flow series at KBFU head, Keenjhar lake, KBF lower, PQ Fall and KG canal regulators have been developed for studying water balance (presented in Figure 7).

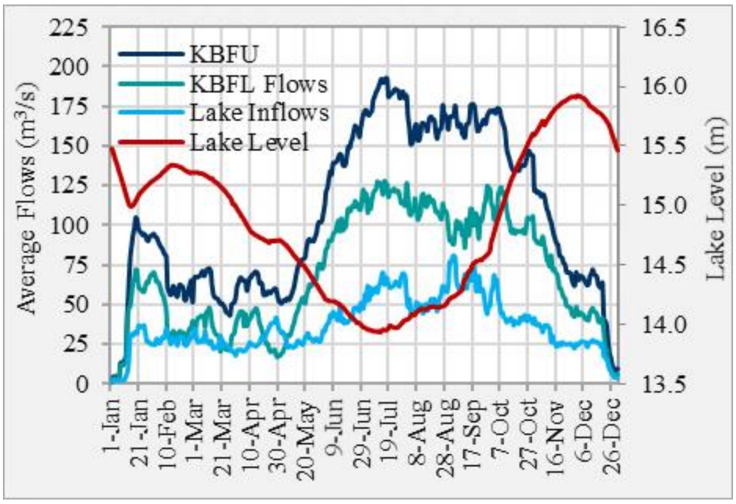


Figure 7. Average Flow Series at KBFU, KBFL & Lake Regulators and Lake Historic Levels

The data of offtakes from KBFU has been collected and rainfall-runoff analysis of the streams draining into the lake (having catchment area of 1,800 sq. km (700 sq. miles)) has been carried out. Further, evaporation losses from the system have also been incorporated in water balance study. Reservoir operation study of the lake (s) has been carried out to ascertain the requirement of additional supplies in view of available flows. A excel worksheet model has been developed; lake inflows, outflows and change in storage are the major components of the operation. Inflows are fed from lake regulator with occasional runoff from the streams; KG canal, PQ Fall and evaporation losses are considered as outflows whereas fluctuation in lake levels has been taken as change in storage. Adopted components of the water balance are presented in Figure 8. Since, additional water supply to Karachi shall be managed through K-IV therefore, phased operation of K-IV (260 MGD for 1st and 390 MGD for 2nd phase) [25] has been considered in the operation.

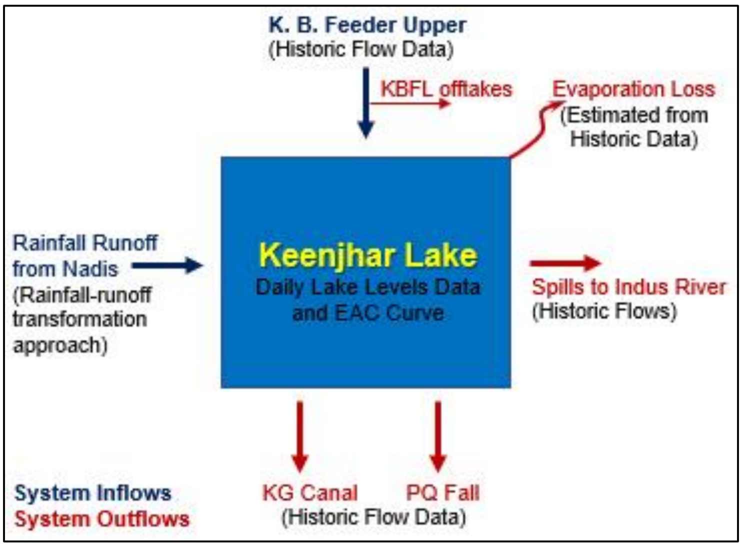


Figure 8. Components of Water Balance

4.3. Present Operational Scenario of Keenjhar Lake

Existing operational scenario of the lake has been replicated using reported inflow data series and model generated lake levels have been checked with that of reported lake levels. It has been ascertained that the system in its present operation shall not be able to meet any additional demand as the system tends to produce shortage under present inflows. Hence, additional supplies to the system are indispensable. The results of the operations are presented in Figure 9 and show that the lake reaches to its dead storage before onset of next wet season hence, necessitating the increased inflows to the lake. Extra flows shall help in continuous direct supply of water with small contribution from the lake and the lake filled in during the wet season may be utilized in dry season.

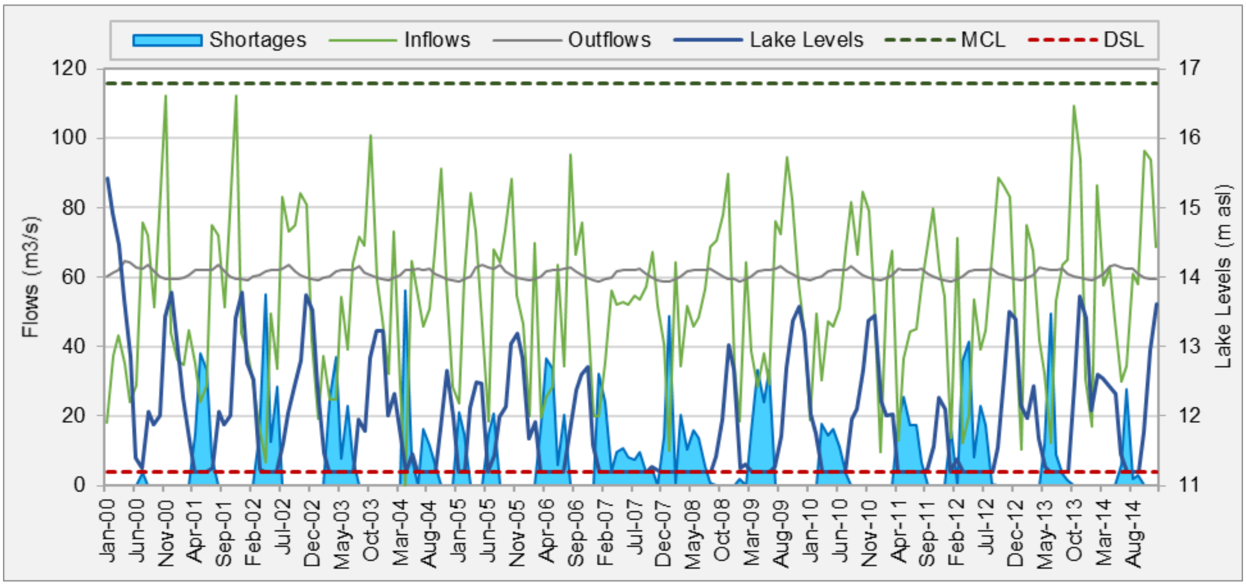


Figure 9. Keenjhar Lake Operation under Present Inflows for Phase-1 of K-IV (260 MGD)

4.4. Proposed Management Approach

The proposed approach suggests the action plan for managing additional flows and storage/ depletion pattern of the lake for uninterrupted water supply. Since, it has been established that additional flows to the existing system are indispensable, the problem can be approached in two different ways: the ideal case would be of adding all the additional required water into the system and then take it out at K-IV, which is impossible on the face of scarce/ seasonal availability of water resources. The other feasible option is the utilization of excess flood flows during wet period; tapping those flows at Kotri, feeding into KBFU and then storing at available storages, which may be utilized year-round. Hence, magnitude and time distribution of flows at Kotri has been studied. Moreover, historic data of KBFU shows that it has never been operated at its design discharge of 9,100 ft^3/s so, restoration of KBFU to its design is indispensable for it to carry additional flows. Next challenge is formulating a trade-off between available excess flows, volume of available storages and the volume of water required to be stored till the next wet season is at the door. The analysed scenarios are: a) availability of additional flows in the system (Sindh accorded allocations and share in flood spills); b) increasing the inflows to the system; and c) evaluation of system capacity to carry/ store the additional flows for the complete year.

4.5. Evaluation of Additional Supplies at Kotri Barrage

Water availability at Kotri d/s (in addition to environmental flows) has been studied and the analyses of flows at Kotri barrage (Figure 10) suggest that the water has always been plentiful during the summer flood period starting from July to mid-September, with flows reducing during the recession towards end of the year with expected occasional small rise near April.

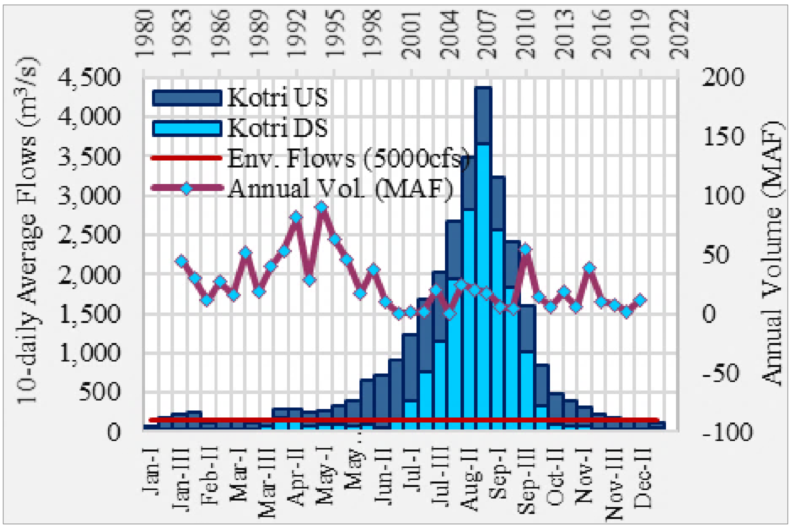


Figure 10. Flows Availability at Upstream and Downstream of Kotri Barrage (WAPDA)

Irrigation water demand at Kotri Barrage is far greater than Karachi's requirements, so the total water requirement at Kotri is very seasonal. Historic data at Kotri shows that that plentiful amount of water (average of 26 MAF) is being wasted into the sea almost every year. Hence, wastages at Kotri minus the environmental flows of 5,000 CFS, have been analysed in consideration of KBFU system carrying capacity and available storages volume. Revamped KBFU shall be operated at its design of 9,100 CFS whenever excess flows are available at Kotri.

4.6. Scenarios Development

For the operation of Keenjhar lake, various scenarios have been developed by adopting synthetic inflow series and phased demand of 260 and 650 MGD. The adopted scenarios are:

- Augmenting the lake inflows by lining KBFU; and
- Diverting flood spills from Kotri downstream (in excess of environmental flows).

In scenario-1, the excess water saved from seepage recovery has been diverted into the lake and in scenario-2, lined KBFU has been operated at its design discharge of 9,100 CFS, whenever excess flows are available at Kotri. Whereas, KBF lower canal has been operated at its historic discharge. The comparison of synthetic inflow series is presented in Figure 11. The additional flows available for each scenario are 0.13 MAF and 0.74 MAF annually, respectively. The results of operational scenario are presented in following section.

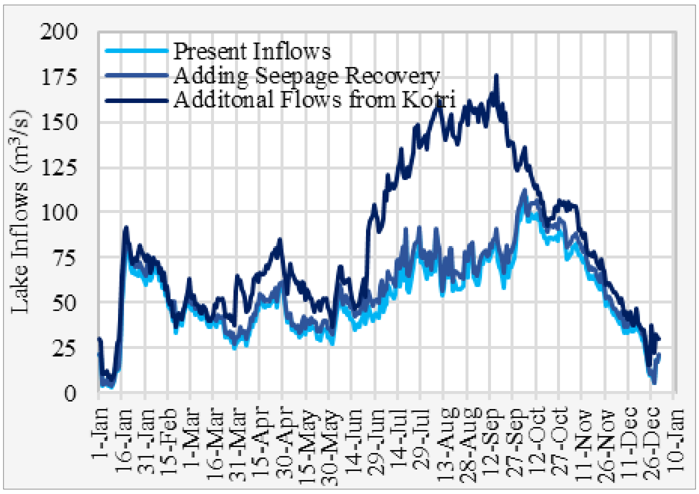


Figure 11. Present and Synthetic Inflow Series

4.6.1. Scenario-1: Present Inflows

Keenjhar lake operation has been carried out for adopted three scenarios of inflow conditions i.e., present flows and two additional inflow series as discussed above. The results show that the system in its present flows is unable to meet any additional demands. Average volume of the shortages encountered equals to 0.20 MAF whereas maximum annual volume equals to 0.33 MAF. Results of the operation are presented in Figure 12.

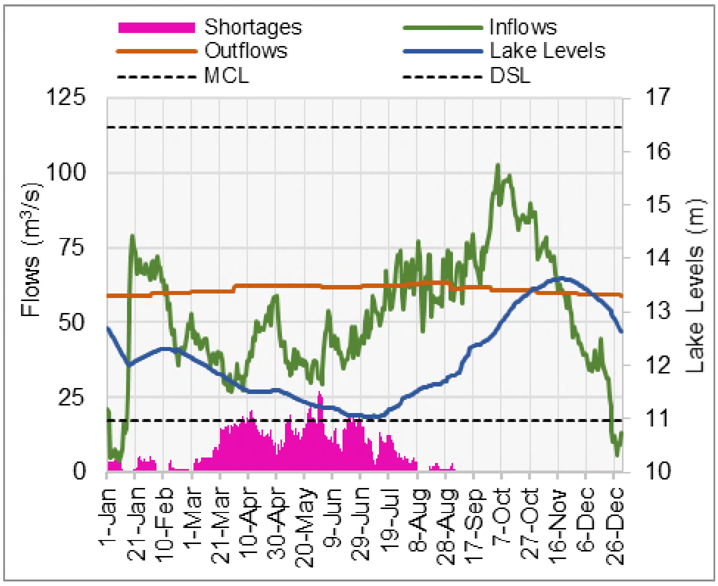


Figure 12. Operation with Present Inflows for 260 MGD Demand

4.6.2. Scenario-2: Additional Inflows into the Lake (Lined KBFU)

Additional flows of 0.14 MAF saved from seepage have been fed into the lake. In this scenario shortages days and volumes have been reduced whereas, the system is still unable to fully meet the demand of 260 MGD and furnished the average annual shortages volume of 0.110 MAF (maximum = 0.237 MAF) and 0.612 MAF for 650 MGD demand. Hence, increased flows are required to meet the water demands.

4.6.3. Scenario-3: Additional Inflows into the Lake (Support from Kotri d/s Flood Spills)

Increased flows from Kotri barrage, in excess to environmental flows of 5,000 CFS, have been diverted into KBFU and fed into the lake. In this scenario the system meets the demand of 260 MGD whereas, for 650 MGD demand (Figure 13) additional flows of 0.284 MAF are required.

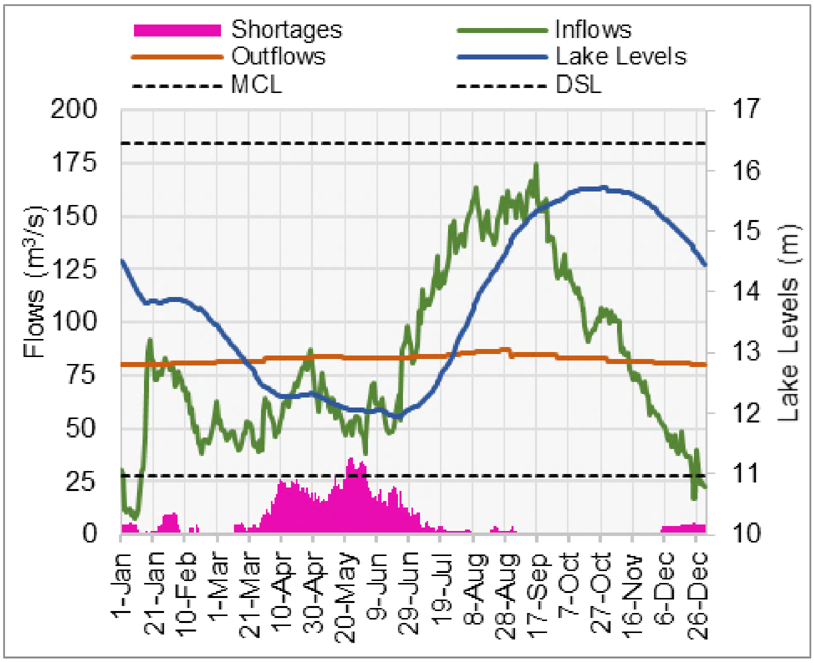


Figure 13. Operation with Additional Flows from Kotri and 650 MGD Demand

4.7. Integrated Reservoir Operations

Three lakes have been integrated to minimize the shortages at Keenjhar Lake. The EAC of the lakes developed from the bathymetric survey suggests that the live storage capacity of Haleji and Hadero lakes is about 0.054 MAF and 0.027 MAF, respectively. The lakes have been operated with the inflows managed from Kotri barrage and having filled the lakes during wet season. The results show that integrating both lakes (with the operation of Keenjhar Lake) provides additional dependence for 14 days and reduces the shortage volume of 0.284 MAF to 0.203 MAF for 650 MGD.

4.8. Suggestions for Operation of Existing Storages

In view of above analyses, tentative operation of existing storages has been summarized below:

- Keenjhar Lake should be filled while River Indus is in flood, if it is to be properly used for primary storage of the excess flood water.
- The period of the greatest water shortages is during the months of May and June; it is during this period that the Kharif flood is expected to rise and, although the flood rise can occur at any time from the beginning of April onwards it can also be delayed until the end of June.
- The flood rise is unpredictable and one of the primary purposes of Keenjhar Lake should be to provide security to Karachi water supply during May and June. One mode of operation of the lake would therefore be to fill the lake during the period July to mid-September and not deplete the lake until February; from February until June the lake could be depleted only for supplying Karachi.
- The proposed rules for operating Keenjhar Lake can be summarized as follows (Table 1):

Table 1. Proposed operational rules for the Keenjhar Lake

July to mid-September	Fill the lake to normal retention level to provide water to Karachi and manage all irrigation through link canal.
Mid-September to end of December	Irrigation indents to be placed at Link canal and supply water for Karachi from the lake.
January to February	Refill the lake during this period in addition to supplying water to Karachi and manage all irrigation through Link canal.
March to June	Basic irrigation flows may be managed through Link canal. Short term fluctuations arriving from KBFU may be fed to the lake. Provide a supplement to the irrigation flows through the Link canal from the lake by PQ Fall regulator. Provide Karachi's water supply by depleting the lake.
June	If the river flows are rising and it is expected that there will be sufficient supply by the mid of June, provide additional irrigation water by depleting the lake.

5. Conclusions and Recommendations

The conclusions and findings of the study are formulated as below:

- The present system is unable to meet any additional demand for Karachi; hence, additional supplies to the lake are indispensable;
- Lining and restoration of the KBFU to its design discharge of 258 m^3/s (9,100 ft^3/s) is very crucial as it will minimize seepage losses and shall have capacity to carry additional flows;
- Additional supplies to the lake may be managed either by i) occasionally compromising irrigation supplies to ensure a continuous additional supply of 260/650 MGD or ii) managing flows from Kotri barrage flood spills;
- Managing all required flows from Kotri is the ideal case, which practically isn't possible due to the fixed indents of all four canals off-taken from Kotri and also the fact that no excess flows are available except during the wet season. Hence, excess flows during the wet season have been diverted to the KBFU system, stored, managed, and supplied to Karachi;
- The study formulated the various synthetic inflow series in an attempt to divert the maximum amount of excess flows from Kotri in consideration of the system carrying capacity and the volume of available storages;
- Analyses of flows at Kotri downstream suggest that the flows have always been plentiful during the wet season (July through October). As of historic data, the average annual flows being wasted into the sea are of the magnitude of around 29 MAF, whereas the environmental flow requirement is a mere 3.6 MAF;
- Revamping KBFU to its design and diverting additional flows enabled the system to meet the demand of 260 MGD, whereas, occasional shortages have been observed for 650 MGD;
- Integration of Haleji and Hadero lakes into the system provides very little support provided the fact that they have very small storage capacities, shallow depths, and escalating evaporation rates that make them run dry very quickly. Hence, the proposals for raising both these lakes or merging all these lakes into a large single storage volume may add to the benefits;
- Further, it is also suggested to raise the Keenjhar lake by 2 ft. up to the level of 56 ft., as the historic data suggest that the lake spillway has never been operated. Rising shall provide additional volume of 0.07 MAF;
- Since the command area of KBFU is mostly water-logged therefore, efforts should be made to line the irrigation network. The water saved by lining may add up to the available useable flows;
- There is much room available for optimizing the irrigation demands. A changed and improved cropping pattern in the face of prevailing waterlogging and water stress scenarios will do a great favour. For example; oil seed crops may be adopted instead of high-water requirements crops of sugarcane etc.;
- First-hand site information suggests that the system suffers substantial losses in terms of water theft and transmission losses, etc. Therefore, authorities should make maximum efforts to moderate such losses in irrigation and domestic supplies.
- KW&SB efficiency may be enhanced by:
  - Reducing planned and unmanaged water thefts in the form of tanker mafia.
  - Improving and replacing the old and leaking water supply network.
  - Unaccounted for and non-revenue water (45-50%) may be reduced as per international practices (6%).
  - Unmetered water supply and private/ illegal connections by boring into the KWSB main lines should be discouraged.

6. Declarations

6.1. Author Contributions

Conceptualization, M.T.; methodology, M.T.; formal analysis, M.T.; writing—original draft preparation, M.T.; writing—review and editing, M.T., Y.A., and M.W.H.; visualization, M.T., Y.A., and M.W.H. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

The author received no financial support for the research, authorship, and/or publication of this article.

6.4. Institutional Review Board Statement

Not applicable.

6.5. Informed Consent Statement

Not applicable.

6.6. Declaration of Competing Interest

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the author.

7. References

[1] Taylor, T, & Goldstein, R. (2010). Sustainable Water Resources Management, Volume 3: Case Studies on New Water Paradigm. Electronic Power Research Institute (EPRI), Palo Alto, United States.

[2] Mehboob, M. S., & Kim, Y. (2021). Effect of climate and socioeconomic changes on future surface water availability from mountainous water sources in Pakistan's Upper Indus Basin. Science of the Total Environment, 769, 144820. doi:10.1016/j.scitotenv.2020.144820.

[3] Chartzoulakis, K., & Bertaki, M. (2015). Sustainable water management in agriculture under climate change. Agriculture and Agricultural Science Procedia, 4, 88-98. doi:10.1016/j.aaspro.2015.03.011.

[4] Frenken, K. (2012). Irrigation in Southern and Eastern Asia in figures: AQUASTAT Survey-2011. Water Reports, FAO Land and Water Division. Available online: https://www.ipcinfo.org/fileadmin/user_upload/faowater/docs/WR_37_web.pdf (accessed on June 2022).

[5] Vallee, D., Margat, J., Eliasson, A., & Hoogeveen, J. (2003). Review of world water resources by country. Food and Agricultural Organization of the United Nations (FAO), Rome, Italy.

[6] Flint, R. W. (2004). The sustainable development of water resources. Water Resources Update, 127, 41-51.

[7] Hassan, M. (2016). Water security in Pakistan: Issues and challenges. United Nations Development Programme Pakistan, 3(4), 1-34.

[8] Mustafa, D., Akhter, M., & Nasrallah, N. (2013). Understanding Pakistan's water-security nexus. Institute of Peace, Washington, United States.

[9] Siegmann, K. A., & Shezad, S. (2006). Pakistan's water challenges: a human development perspective. Working paper Series # 105, Sustainable Development Policy Institute, Islamabad, Pakistan.

[10] Siyal, A. W., Gerbens-Leenes, P. W., & Nonhebel, S. (2021). Energy and carbon footprints for irrigation water in the lower Indus basin in Pakistan, comparing water supply by gravity fed canal networks and groundwater pumping. Journal of Cleaner Production, 286, 125489. doi:10.1016/j.jclepro.2020.125489.

[11] Birdsall, N., Kelley, A. C., & Sinding, S. W. (2001). Population Matters: Demographic Change, Economic Growth, and Poverty in the Developing World. Oxford University Press, New York, United States. doi:10.1093/0199244073.001.0001.

[12] Brown, R. R., Keath, N., & Wong, T. H. F. (2009). Urban water management in cities: historical, current and future regimes. Water Science and Technology, 59(5), 847–855. doi:10.2166/wst.2009.029.

[13] Young, W. J., Anwar, A., Bhatti, T., Borgomeo, E., Davies, S., Garthwaite III, W. R., Gilmont, E. M., Leb, C., Lytton, L., Makin, I., & Saeed, B. (2019). Pakistan Getting More from Water. Water Papers, World Bank Group. doi:10.1596/31160.

[14] Watkins, K. (2006). Human Development Report 2006-Beyond scarcity: Power, poverty and the global water crisis. UNDP Human Development Reports (2006), United Nations-Human Development Report Office, New York, United States.

[15] State Bank of Pakistan. (2017). Annual Report of State Bank of Pakistan (2016-2017). States bank of Pakistan, Karachi, Pakistan. Available online: https://www.sbp.org.pk/reports/annual/arFY17/Anul-index-eng-17.htm (accessed on March 2022).

[16] Islam-ul-Haque, L. C., & Falak, J. (2018). Water Resources Management Karachi: The Uroos-ul-Bilaad. Mitigation Intervention & Strategies to Enhance Safe Drinking water Availability and For Improved Health and Hygiene Environments, Centre for Peace, Security and Development Studies (CPSD). Available online: http://www.cpsd.org.pk/img/Water-crisis-management-Report.pdf (accessed on June 2022).

[17] Ahmad, M., & Burki, S. J. (2016). Water crisis in Karachi: old issues needing a new look. Business Recorder. BIPP Policy Brief 29/2016. Available online: http://www.sjbipp.org/publications/PB/pdf/PB-29-16.pdf (accessed on March 2022).

[18] Bhutta, M. N., Chaudhry, M. R., & Chaudhry, A. H. (2005). Groundwater quality and availability in Pakistan. Proceedings of the seminar on strategies to address the present and future water quality issues, 6-7 March, 2002, Council of Research in Water Resources, Islamabad, Pakistan.

[19] Hasan, S. (2013). The 12 remaining Dumlottee wells. Dawn News. Available online: https://www.dawn.com/news/1033855 (accessed on June 2022).

[20] Hasan, S. (2015). Hub dam water level rises to 289 feet. Dawn News. Available online: https://www.dawn.com/news/1197188 (accessed on March 2022).

[21] WWF Report. (2019). Situational Analysis of Water Resources of Karachi. Project Funded by the European Union. Available online: https://d2ouvy59p0dg6k.cloudfront.net/downloads/report___situational_analysis_of_water_resources_of_karachi.pdf (accessed on March 2022).

[22] Wajdi, M. A. Z. (1992). A Study of the Legal and Constitutional Development of Municipal Administration in Karachi from 1933 to 1946. Journal of the Pakistan Historical Society, 40(2), 161-174.

[23] NesPAK (2018). "Feasibility Study of Present Network of Kalri Baghar Feeder and Keenjhar Lake and Suggesting Measures for Up-Gradation of the Same to Enhance Water Requirement from Keenjhar Lake to Karachi Water and Sewerage Board (KW&SB)". National Engineering Services Pakistan NES, Lahore, Pakistan. Available online: https://www.nespak.com.pk/pdf/MDR-18-PDF.pdf (accessed on March 2022).

[24] NesPAK (2021). Third Party Design Review of the Greater Karachi Bulk Water Supply Scheme K-IV Project. National Engineering Services Pakistan NES, Lahore, Pakistan. http://www.wapda.gov.pk/index.php/projects/water-sector/o-m/kachhi-canal-project/item/646-the-greater-karachi-bulk-water-supply-scheme-k-iv (accessed on March 2022).

[25] Kazmi, S. J. H., Shaikh, S., Tamiz, I., Khan, S., & Arsalan, M. H. (2015). EIA of K-IV Project: jointly conducted by University of Karachi, Osmani & Company and KW&SB, Karachi, Pakistan.