Thar Coalfield water impacts

Financial and social risks

Paul Winn
Hydrocology Consulting

AUGUST 2020

Executive summary

Development of the Thar lignite deposit in Pakistan's Sindh Province for thermal power generation presents substantial risks of significant water conflict with irrigators and food and fibre production in the Indus Basin, as well as the effective removal of the sole reliable water source for many Thari people. This report demonstrates that Thar coal project proponents and Pakistani governments have severely overestimated groundwater availability.

The Pakistan Government hopes to see between 6 and 10 Gigawatts (GW) of power generation capacity installed on Sindh's Thar Lignite deposit. To date, two coal-fired power units have been commissioned, one is under construction, two have reached financial close, and a further two are in planning.

Thermal coal power generation requires vast volumes of water for cooling. While questionable volumes of highly saline fossil groundwater are available, no permanent local surface water sources exist. The high net annual evaporation means groundwater recharge is low. The deepest aquifer has been identified to supply most of the Coalfield's water demand. This aquifer flows from about 200km northwest in India, over a fall of just 20m. The deeper aquifers drain into the Ramsar-listed Rann of Kutch wetland, 25km south of the Coalfields, at a horizontal flow rate of less than 10m a year.

The first of three open pit mining projects is operating, one is under construction, and a third has yet to reach financial close. As the deepest and most extensive aquifer is drawn down sufficiently to allow open pit mining to proceed, adequate water for thermal power cooling water will not be available. In addition, many Thari people will lose access to reliable groundwater for generations.

Based on the information provided in official documents, and our projections considering predicted dewatering rates, evaporation, and losses due to the necessity to desalinate the groundwater for thermal cooling, the gap between the water required for the projects and what is available from mine dewatering is staggering. The deficit between maximum mine dewatering rates and the raw water demand of all proposed plants operating at 75 percent load is in the order of 100 billion litre a year (GLpa), increasing to about 150 GLpa after 25 years of mining.

Two surface water diversion schemes from the Indus Basin Irrigation Scheme (IBIS) are proposed, but all the proposed fresh water is currently allocated to irrigation. A 40 GLpa surface water diversion from one of the main irrigation canals of the Indus Basin Irrigation Scheme, and another wildly expensive scheme for 31 GLpa of saline effluent from the highly contaminated Left Bank Outfall Drain, have faced cost overruns, difficulties and delays.

The Sindh is extraordinarily dependent on its water infrastructure, but due to a combination of age and neglect, much it is inoperative, and none of the major components have modern Asset Management Plans. However, the Province's economy is heavily dependent on irrigation and vulnerable to adverse weather conditions. A recent Needs Assessment identified drought, or drought like conditions prevailing in Sindh Province since 2013. Thar Coalfield water diversions are planned to be extracted from the most drought-affected Districts of Sindh Province.

Our analysis finds in summary that;

* The volumes of water to be abstracted as part of mine dewatering may be considerably over-estimated given the hydrogeological properties of the area and a lack of knowledge of the characteristics of the deepest aquifer.
* In any case, groundwater removal is likely to affect the water supplies of many of the 1.65 million Thari, removing the sole permanent water supply for many and leaving them reliant on treated water supplied by mining and power companies.
* The volumes of water required to run the proposed power stations have been underestimated.

* Surface water diversion from the Indus Basin Irrigation Scheme will be necessary to supply water at the volumes needed to run the power stations, but no assessment has been undertaken of the environmental, social and economic impacts of such diversions.

* These are likely to be considerable, given the central importance of agriculture to Pakistan's economy, existing high rates of malnutrition, livestock losses and monsoon failures and projections of reduced water availability and crop yields as a result of climate change.

* Diversion of irrigation water to supply industry is contrary to Pakistan's National Water Policy, unsurprisingly, since agriculture is crucial to the country's economy and food supply.

* In any case, the aging canal infrastructure of the irrigation scheme may not be able to support water delivery at the required volume.

* Plans to supplement water supply from existing effluent sources like the Left Bank Outfall Drain are cost-prohibitive because of water treatment expenses for this heavily-polluter water.

* Forecasts of intensifying water shortages due to worsening water security have not been accounted for in power station planning.

* The scheme may trap Pakistan and Sindh governments in circular debt if loan terms require capacity payments and water scarcity prevents operation of the power stations at full capacity.

In short, fossil groundwater abstraction cannot reliably supply extensive electricity generation on the Thar Coalfields, when mine use, water treatment, local population potable water and evaporation losses are considered. As large surface water diversions from the IBIS will significantly disrupt existing irrigation, with the potential for political tensions and social unrest, further development of the Thar coal project poses significant financial and social risk.

Thermal power generation on the Thar Coalfields must be reevaluated. Unless significant power generation capacity is cut from current plans, devastating impacts need to be forced onto irrigation and food and fiber production in the Sindh.

Contents

Conversion factors

Water Volume
- Ft^3 (Cubic feet) = 0.0283168 m^3 (cubic meters)
- MAF (Million acre feet) = 1,233.48 GL
- G (gallons) = 4.54609 L (litres)

Water Flow
- Cusec (Cubic feet per second) = 0.028316847 cubic meter/second
  - = 893,593,381 litres /year
  - = 0.9 Gigalitres/year (Glpa)
- GLpa (Gigalitres per year) = 1 billion litres/year
  - = 1.12 cusecs
  - = 810.714 acre feet

Electricity
- MW (Megawatts) = 1 million watts
- GW (Gigawatts) = I billion watts
  - = 1000 Megawatts

Weight
- T (Tonnes) = 1000kg
  - = 2204.62 lb
- Mt (Megatonnes) = 1,000,000 tonnes

Pressure
- Mpa (megapascals) = 1,000,000 pascals
  - =145.038 psi (pound per square inch)

Length
- mm = 0.001 m
  - = 0.0393701 inches
- inch = 25.4 mm
- Km (kilometer) = 1000m
  - = 0.621371 miles

Area
- acre = 0.404686 ha (hectare)
  - = 0.00404686 km^2 (square kilometers)
- hectare = 10,000m^2
  - = 2.47105 acres
  - = 0.00386102 square miles
  - = 0.01km^2

Introduction

Financial, social, and environmental risks are associated with the development of mine mouth thermal electricity generation in the District of Tharparkar in Sindh Province financed under the China Pakistan Economic Corridor (CPEC).[1]

The Thar Coalfields sit in the southeast corner of the Thar Desert, with a population of 1.65 million. To exploit the vast lignite (brown coal) deposits, the Coalfield has been divided into blocks for mining development. Six blocks have been explored, each with measured deposits of between 400 and 800 million tonnes (Mt).

The Sindh Government hopes to see between 6 and 10 Gigawatts (GW) of power generation capacity installed. However, thermal power generation requires large volumes of clean cooling water. While uncertain volumes of highly saline fossil groundwater are available, no local surface water source exist in the immediate area.

Hydrogeological modeling and pump testing of groundwater and geochemical analyses suggest little or no groundwater recharge, suggesting this resource is non-renewable.[2] The very poor Environmental and Social Impact Assessments (ESIA) for the coal projects provide no clarity on the potential impacts open pit mining will have on groundwater behavior, particularly for the vast artesian aquifer below the coal seams.

The Sindh Government is proposing a large surface water diversion to supply water from the Indus Basin Irrigation Scheme (IBIS) to the Thar Coalfield. Pakistan's economy depends on irrigation. However, Pakistan is ranked third among the countries facing severe water shortage,[3]and declining per capita water availability predicted in 2025 would make Pakistan a "water scarce" country.[4]In 2017, a food security assessment for Tharparkar, Umerkot, Sanghar and Jamshoro Districts found very high food insecurity.[5]

This report seeks to identify the underlying water supply risks to thermal power generation on the Thar Coalfields.

1 CPEC, 2020.
2 Geyh et al 2008.
3 Nabi. *et al.*2019: Kalpana et al 2015.
4 GoP, 2018.
5 Pakistan Food Security Cluster, 2017.

Thar Project summary

The Thar Coalfield was discovered in 1992. Long delays have been experienced in exploiting the resource for thermal power generation. Indeed, in 2016, a number of Thar projects faced exclusion from the CPEC due to delays.[6]

Mining is now underway in Block II.[7]The Block I[89] integrated mine and 1320 MW power plant reached financial close in February 2020, and Block VI [10] integrated mine and 1320 MW plant. It has now announced its intention to building of 2x660MW units in phase 1 and is 12-18 months from financial close. All coal mines are open pit.

Indications of cost overruns have emerged. Sino Sindh Resources (SSRL), the developer Thar coal Block I, recently sought a 12.5 percent increase in the coal tariff to USD50.6 a ton from USD44.50 a ton as the project entered engineering, procurement and construction.[11]

Table 1: Thar mine block summary

Block	Status	Company	Capacity (Mtpa)	Area (km2)	Bores #	Coal seam (m)	Depth (m)	Measured coal (MT)
I	FC: 2/2020	Sino Sindh Resources	7.8	122	43	8 to 36	137-189	620
II	Operating	Sindh Engro Coal Mining Company (SECMC)	6.5-22.8	55	43	7.5-31	117-166	640
III	Abandoned	Cougar Energy (UK)		99.5	41	7.2-25	114-203	413
IV	Exploration	Oracle coalfields PLC (UK)		82	42	10.7-33.45	117-166	684
V	Abandoned	Pakistan government		63.5	35	16.74-30.9	177-166	637
VI	FC expected 12-18 months	Sindh Carbon Energy Ltd. (SCEL)/ Oracle (UK)	7.8 - 16	66.1	35	9-20.7	115	762
Totals			**22.1 - 46.6**	**488.1**	**239**			**3756**

6 Shahbaz Rana, 2016.
7 Hagler Bailly, 2012.
8 Environmental Management Consultants, 2012.
9 Naeem et al, 2018.
10 Hagler Bailly 2013.
11 Javed Mirza, 2019.

Four thermal plants are planned for Block II:

- Engro thermal plant of two 330 Megawatt (MW) [12] units commissioned in June 2019;
- Thar Energy Limited 330MW plant[13] under construction;
- ThalNova's 330MW plant reached financial close in January 2020; and
- Sidiqsons 330MW plant is nearing financial close.

Table 2: That power plant summary

Coal source	Plant	Parent	Units (MW)	Capacity MW)	Status	Technology
Block II	Engro Powergen	Engro Powergen Ltd (EPL) (50.1%)/China Machinery Engineering Corporation (CMEC), Habib Bank Ltd (HBL), and Liberty Mills Limited	2x330	**660**	Operating	Subcritical pulverized
Block II	Thar Energy Limited (TEL)	Hubco (60%), Fauji Foundation (30%), CMEC (10%)	1x330	**330**	Construction	CFB
Block I	Thar SSRL	Sino-Sindh Resources (SSRL) - Shanghai Electric/Global Mining (China)	2x660	**1320**	FC: 2/2020	Subcritical
Block II	ThalNova	Hubco (37%), Thal Limited (31.5%), CMEC (10%), Other (20.5%)	1x330	**330**	FC:1/2020; CO: exp. 1/2022.	CFB
Block II	Siddiqsons	Siddiqsons Group -Harbin Electric International Company/Engro Corporation	1x330	**330**	FC: in progress. CO exp. 6/2021	Supercritical
Block VI	Oracle Power	· Sindh Carbon Energy Ltd (SCEL) - Oracle Power (UK) - 73% China Coal, 15% Sheik Al Maktoum's private office, 12% Oracle Power.	2x660	**1320**	FC: exp. 12-18mths	CFB
TOTALS	**6**		**9**	**4290**		

12 Hagier Bailly, 2014.

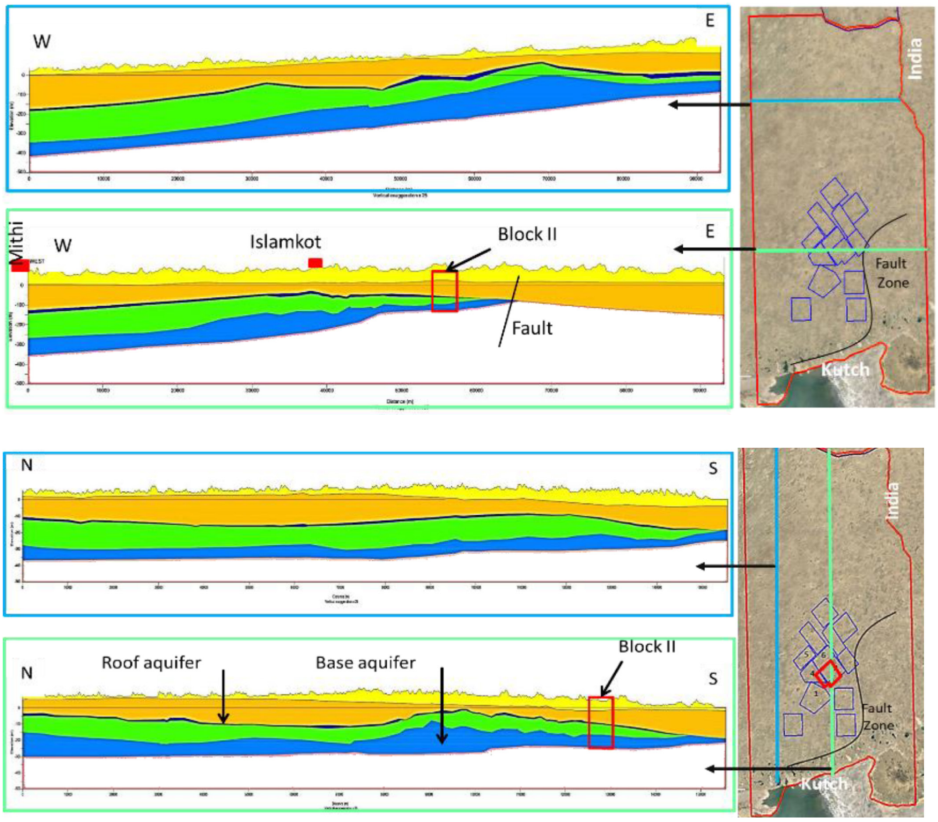
13 Hubco, 2020.

Hydrogeology

Two significant unpublished reports by China's Northeast Coalfield Geological Survey Bureau in 2005,[14]and another written as part of a Bankable Feasibility study in 2010, are the basis of much of the hydrological understanding of the Thar Coalfields. Subsequent drilling and bore pump testing for the three mining ESIAs have provided a reasonable picture of the hydrogeology within the three active coal blocks. However, much of the regional groundwater picture rests on the 1994 USGS report that first described the Thar lignite deposit.

The 1994 USGS report[15] suggests the granite basement of the Thar Coalfields was uplifted in the Late Cretaceous dipping to the west. The lignite was deposited in the Paleocene to Early Eocene. Relatively recently, the Coalfield was traversed by the ancestral Indus river system resulting in deposition of the alluvium layer present throughout the area. The Thar fault in the southeast part of the Coalfield also probably formed at the same time, resulting in the coals east of the fault being uplifted and removed by erosion. The dunes of the Thar Desert began to form about 20,000 years ago.

Figure 1: North south and east west hydrogeological profiles of Thar Coalfields showing coal Blocks, Thar Fault, Rann of Kutch, and groundwater model area (Taken from SECMC & Engro, 2018).



14 USGS, 2008.

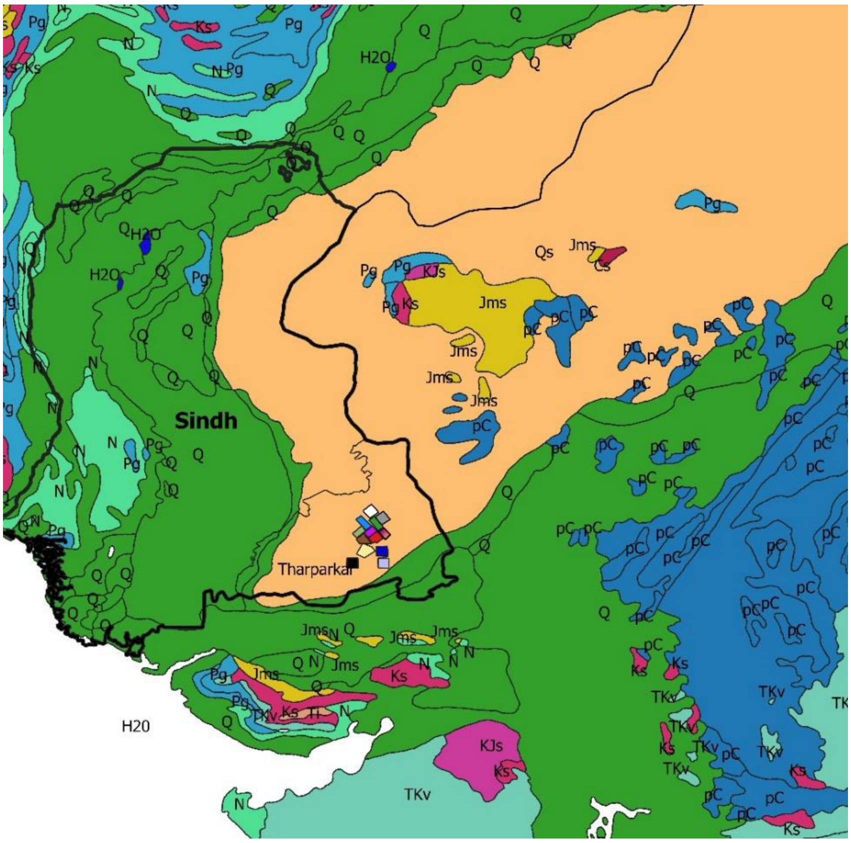
15 Fassett et al, 1994

Three aquifers exist below the mine area (See Figure 1). The first, a sand dune aquifer, is largely ephemeral and patchy. The second, much older, confined aquifer is more consistent and probably marginally connected with the shallow dune aquifer. The third and deepest confined aquifer is under artesian pressure (7Mpa) and extends across into India.

Although the groundwater in Sand Dune Aquifer is recharged by monsoonal rainfall, the groundwater in the two deeper aquifers flows from India where the sediments subcrop beneath the sand dunes about 200 km to the northeast of the Thar Coalfield.[16] The deep groundwaters of the Thar are generally paleowaters with ages ranging from 4,000 to 9,500 BP.[17] Recharge to these aquifers is likely to be negligible or non-existent.[18] The nearest major surface outcropping is of Jurassic origin about 125 km north east from the Coalfield in India (See Figure 2). Minor outcropping of basement granite exists in Nagparkar to the southeast.

The bottom and intermediate aquifers probably drain into the Rann of Kutch, a saline wetland 25km to the south of the Coalfield. However, with the exception of the Thar Fault, aquifer connectivity is poorly understood.

Figure 2: Regional surface geology showing coal blocks and surface outcropping (GIS data from Wandrey and Law, 1998).



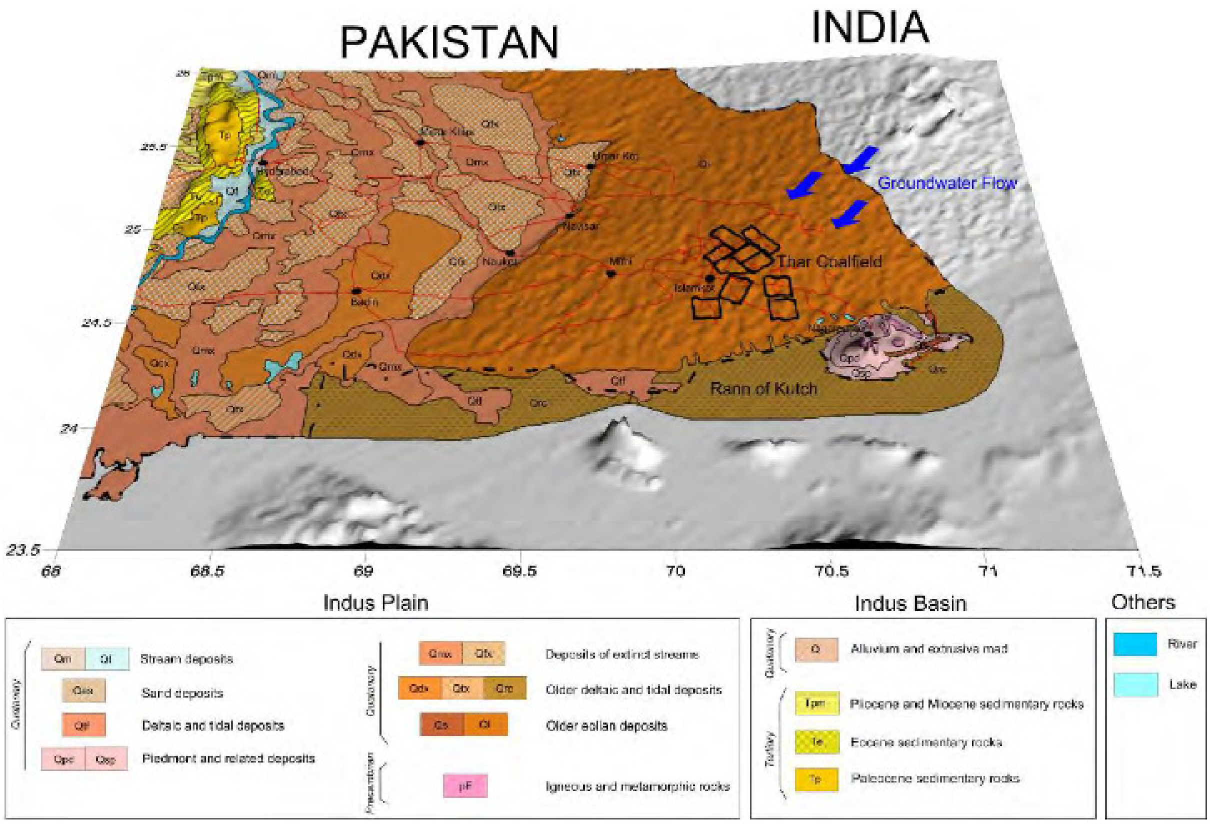
Highly porous sandstone aquifers, such as the bottom coal seam floor aquifer, are often heavily fractured with faults, bedding planes and strata-bound joints representing preferential pathways for water. However, seismic surveys were not undertaken to confirm whether connectivity exists between the three aquifers.

The granite basement floor of the bottom aquifer dips sharply to the west of the Coalfields where it is highly fractured.

Indeed the underground mines of the Lakhra Coalfields, 200km to the northwest, where mines extract coal from the same seam as the Thar Coalfield mines (Bara formation), have no groundwater inflows.[19] This provides good evidence that the deeper aquifers of the Thar drain into the Rann of Kutch and the Thar Coalfields are at the bottom end of the aquifers' flow.

16 JICA. 2013.
17 Nair et al, 1997
18 Geyh et al, 2008.
19 JICA, 2013.

Figure 3: Subsurface geology of Lower Sindh and India showing groundwater flow and surface features (Taken from JICA, 2013).



The bottom coal seam floor aquifer, which sits immediately below the Bara coal seam, is estimated to cover an area of about 15,000 km2. Modelling for Block II presumes a very high porosity of the bottom aquifer of 30 percent, higher than for the pure sand Dune Aquifer (25%).[20] Based on this high porosity, Sindh Engro Coal Mining Company (SECMC) has estimated that beneath the 9,100 square kilometer Thar coal deposit area is approximately 67,000 – 73,000 GL of groundwater.[21] However, the structural dome on which the coal seam sits, narrows the depth of the bottom aquifer to the east (See Figure 1).

The mining area is at the down gradient end of a very slow moving groundwater system. The gradient of the bottom aquifer estimated from north to south is 10 to 15 m over a distance of 120km, and horizontal flow is estimated to be between 1 to 10 meters a year.[22]It may take more than 10,000 years for the deep groundwater to pass through the modeled area, 104km from north to south.

The groundwater model area does not extend to the aquifers full areal extent, which has not been described. Drilling for Fassett *et al*, 1994 suggests the aquifer's granite basement contours show a distinct structural dome beneath the Thar Coalfields with little gradient from the northeast (See Figure 5). The deep aquifer is at the bottom end of a large body of groundwater and steeply dips to the west.

The Thar Fault that passes through the southeast of the coalfield defines the southeast no flow boundary of the Thar groundwater model. The groundwater model assumes the Thar Fault forms a barrier to groundwater flow to the south east, and as such the predicted propagation of the cone of groundwater depression, after mine has begun, is to the west and north of the mining area, which will impact dewatering in adjacent mining blocks and water supply for proposed power plants and local villages.[23]

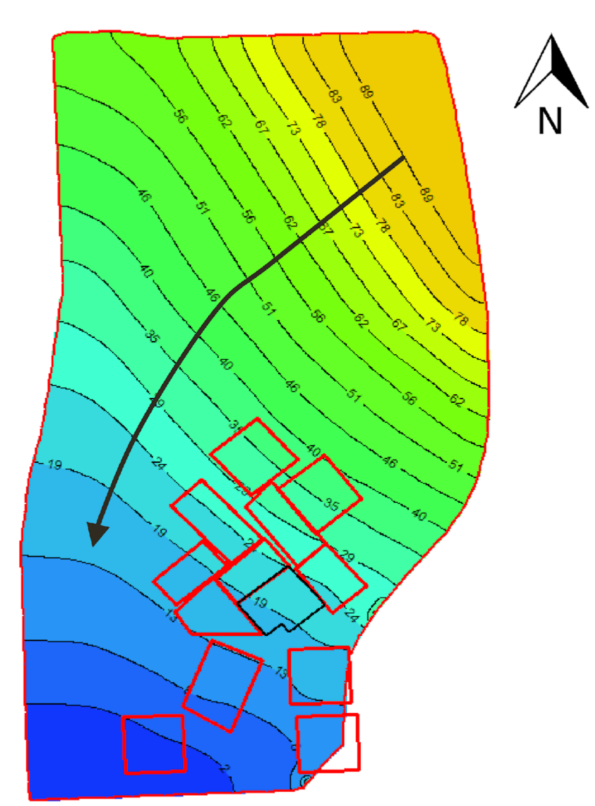
20 JICA, 2013.

21 The News International, 2018.

22 Nadeem, 2019.

23 Nadeem, 2019.

Figure 4: Groundwater flow and groundwater contour (Taken from SECMC & Engro, 2018)



*Groundwater flow from north-East to South-west

Figure 5: Granit basement unit structural contours (Taken from Fassett et al, 1994)

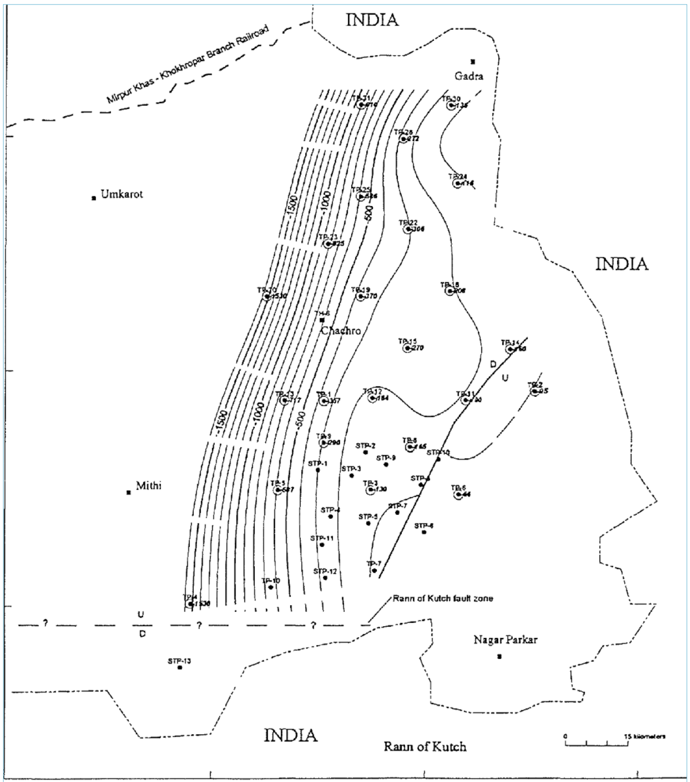


Figure 5. Structure contour map of the Thar coal field area contoured on the top of the granite basement rock. Drill sites used for control for this map are circled. Drill holes that actually penetrated the granite basement are TP-2, TP-3, TP-6, TP-8, TP-14, STP-5, STP-6, STP-8, and STP-10. (This map was generated using the computer-contouring program Surfer, manufactured by Golden Software.) Contour interval is 100 m.

It is not the volume of groundwater that exists below the mine area, or to the west, that relates to the long-term annual mine inflow, but the time it will take for depressurized groundwater to move laterally from the northeast into the coal mine void as it is abstracted, if any northeast flow exists. Figure 5, from Fassett et al (1994), suggests that no basement gradient exists to the northeast and therefore lateral flow would be to the west. The Rann of Kutch Fault Zone, an undescribed area where faulting is thought to exist, must therefore induce any identified north east flow, rather than the aquifers basement gradient.

Nevertheless, as mining continues and more groundwater is dewatered the water table level will drop. If the bottom aquifer is drawn down sufficiently, accessible groundwater may not be available in the immediate surroundings for a considerable period of time.

Mine Dewatering

In 2010, a groundwater model was established by RWE[24]based on an unpublished Northeast Coalfield Geological Survey Bureau report, to predict the dewatering volumes necessary for safe mining conditions in Block II, and estimated 32 dewatering wells needed with annual volumes of 37 GLpa. In 2013, this was revised to 26 wells with annual discharge volumes of 30 GLpa.

Mine dewatering rates are poorly described in the ESIAs with various modeling simulations in hydrogeological reports suggesting vastly different rates of mine inflows. That project proponents and the Sindh Government has expressed concerns for cumulative drawdown. The Sindh Government's 2010 Information Memorandum for the Thar coal development identifies the risk that depressurising the bottom aquifer in one area may interfere "very drastically" with the yield of the dewatering wells in other mines, potentially in the order of 40 percent.[25]

The 2012 Block 2 mine ESIA[26]suggests the cone of groundwater drawdown created by mine dewatering associated with the Block 2 mine is predicted to extend 15 to 20 km from the center of the site. The ESIA goes on to speculate that the cone of groundwater depression may increase with future development of other blocks to an extent "that the cumulative impacts associated with reduced groundwater availability may become nationally or internationally significant by extending to Rann of Kutch and across the border to India". No assessments have been published on the potential impacts on the border population of Gujerat who might lose groundwater access, or at the very least have to contend with significantly extending well depths to access reliable groundwater resources.

Indeed, one report suggests that; "After 30 years of mining operations, models predict a regional cone of depression of similar size and magnitude that extends beyond the model domain to the west and north."[27] If this is the case, most of the District of Tharparker and its 1.65 million Thari could lose access to groundwater, or have to significantly deepen wells and bores.

The behavior of the bottom aquifer in response to mine dewatering may be significantly different than modeled. How it behaves could have consequences for water availability for thermal power generation and groundwater dependent communities and irrigators considerable distances from the mines. Moreover, as mining proceeds, even the very coarse groundwater model and its untested assumptions, predicts the bottom aquifer will not provide the volumes of water required for the reliable operation of those power plants that propose to rely on desalinated groundwater.

According to modeled simulations for Block II, groundwater volumes needed to be pumped will be around 35 GLpa from 2012/2013 up to 2024. Thereafter, the volumes will steadily decrease to 25GLpa and 20 GLpa towards the end of the mining operations. Most of this water is pumped from the bottom aquifer (90%), while the intermediate aquifer and sand dune aquifer will deliver about 9 percent and less than 1 percent, respectively. Table 3 and 4 below sets out the groundwater model settings identified by JICA.

24 RWE International, 2009.
25 GoS, 2010.
26 Hagler Bailly, 2012.
27 Nadeem Arif, 2019.

Table 3: Groundwater model settings, analytical and boundary conditions (Taken from JICA, 2013).

Table 3.4-2 Model Settings, Analytical Condition and Boundary Condition

Model Setting	Area	9,700 km^2
	Perimeter	400 km
Analytical Conditions	Application (Code)	GWDREI
	Analytical Method	Finite Volume Method
	Analysis Period	2012–2100 (89 years) - 2017 mine bottom reached - 2045 end of activities - approx. 2110 groundwater levels stable (i.e., when the final lake shows no rising water table)
	Time step	1 year
	Initial Condition	Observed GW contour
	Aquifer Parameter	Refer to Table 3.4-3
	Analytical Case	Refer to Table 3.4-4
Calibration Model	Effective Recharge	5.15 mm/year
	Shallow Well Abstraction	5.15 mm/year
	Pumping Rate of Deep Tubewells	4 wells - 100,000 gal/day (whole year) - 80,000 gal/day (whole year) - 75,000 gal/day (half year) - 25,000 gal/day (half year)
	Boundary Condition	North, west, and south-west: Interpolated water level South-east: no-flow boundary (Rann of Kutch Fault)
Prediction	Dewatering wells	Total 110 single or multilayer wells of 600 mm diameter
	Infiltration wells	Installation in 2nd Aquifer
	Inside Dump	Kf = 2.0 x 10^{-7} m/s
	Final Lake	Lake Surface Potential Evaporation = 1700 mm/y (1900 mm evaporation – 200 mm rainfall)

Source: Sindh Engro Coal Mining Company (2010)

Table 4: Groundwater analytical parameters and model simulations from Sindh Engro, 2010 (Taken from JICA, 2013).

Table 3.4-4 Analytical Cases

Case	Scenario	Condition
Simulation I	Basic simulation of calibrated model	Refer to Table 3.4-3
Simulation II	The influence of the mine on the first aquifer (Sand Dune)	1st aquitard : Kf = 5.00 x 10^{-8} m/s
Simulation III		1st aquitard : Kf = 1.00 x 10^{-7} m/s
Simulation IV	Infiltration simulation on the basis of Simulation I to minimize the influence on the 1st aquifer	Infiltration rate = some 6 Mm^3/a
Simulation V	Recovery period and development of residual lake without any infiltration and production wells	Potential evaporation = 1700 mm (on the lake surface)
Simulation VI	Determination of the influence on dewatering quantities when the 3rd aquifer has a higher permeability than assumed	3rd Aquifer Kf = 1.50 x 10^{-4} m/s (50% increase)

Source: Sindh Engro Coal Mining Company (2010)

The ESIA for the Block VI[28] mine identified the potentially significant cumulative impact on groundwater supplies. While the SCEL mine does not anticipate dewatering the bottom aquifer, it is planned to pump from bores in the bottom aquifer as a water source for potable water for local communities in the Block, and also to supply water for the subsequent power plant development. The Block VI ESIA does not provide an estimate of its dewatering, stating instead an intention to avoid depresurising the bottom aquifer. However, this is likely to be unavoidable. The deep aquifer is under artesian pressure and will deform the mine floor after the mine reaches about 100 meters.

The long-term capacity of the bottom aquifer appears to be inadequate to supply sufficient water for the needs of Oracle's Block VI power project, as mining and dewatering of the Block VI mine will be concurrent with the dewatering of the Block II, and perhaps also Block I mine.

Block VI ESIA provides required pump rates for mine dewatering. Using these pump rates and the number of bores sunk, less logical declines in dewatering using estimates from Block II, we estimate a peak mine dewatering rate of about 26.6 GLpa, declining to 22.7 GLpa at year 15, and 17 GLpa in about mining year 25.

The ESIA for the Block I mine provides little information on mine inflows, but states that dewatering rates will peak at 25 GLpa, with "normal" dewatering being 8 GLpa. The estimated dewatering rates set out in the ESIAs for Block I and Block II, are 56.8 GLpa, decreasing to 17 GLpa. See Table 5 below.

Table 5: Mine dewatering estimates

Block	Max. ESIA Dewatering estimates (GL/pa)	Min. ESIA Dewatering estimates (GL/pa)	~year 5 Modelled Dewatering estimates (GL/pa)	~year 15 Modelled Dewatering estimates (GL/pa)	~year 25 Modelled Dewatering estimates (GL/pa)
I	25	8	25	13	8
II	31.8	9	31.8	25	20
VI	Negligable	Negligable	26.5	22.7	17
Totals	56.8	17	83.3	60.7	45

Our estimates, based on ESIA modelling (Blocks I and II) and predicted pump rates for Block VI, are a maximum combined rate of about 83 GLpa in the first five years of mining, declining to about 60 GLpa in mining year 15, and about 45 GLpa in about mining year 25.

While estimates for the Block II mine may be acurate, Block I and VI mine estimates have not taken into account the likely 40 percent reduction in mine dewatering rates due to cumulative drawdown. This could reduce dewatering to about 60GLpa after 5 years of concurrent mining.

Moreover, the bottom aquifer has never been described in any detail and little is known of its areal extent. No seismic surveys or detailed bore data from across the aquifer were undertaken to inform the model, and only scant geochemical analyses were completed. The result is a model that cannot adequately predict groundwater hydrodynamics or changes in groundwater behavior that may have consequences for the Thar Coalfield Projects and the 1.65 million Thari who have survived on these groundwater resources for millennia.

Despite these very obvious deficiencies in the groundwater model, project proponents and Pakistan and Sindh Governments present these predictions as fact. If mine dewatering has a greater, or indeed different, impact on the groundwater regime fo the region, it could be disastrous for the Thari people and Pakistan more generally should substantial debts be incurred for thermal power plants that cannot be fully utilised due to a lack of water.

28 Sindh Carbon Energy Limited, 2013.

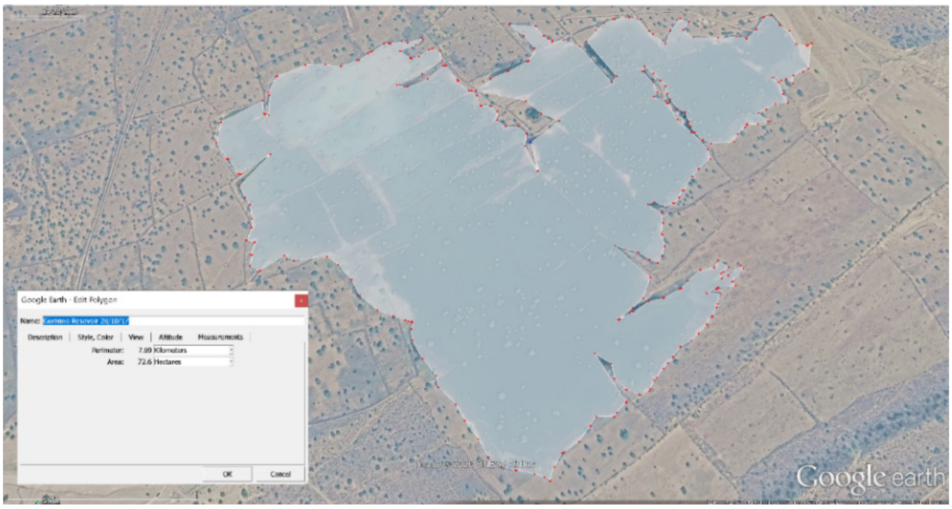
Gorrano Effluent Pond

A presentation by Engro and SECMC on 19 September, 2018, described the 30 GL Gorrano Effluent Pond as a 570 ha natural depression about 26km south of Block 2, which receives mine effluent via a 50 m3/s pipeline from the Block-II Mine,. This would mean the Effluent Pond is about 5m deep at maximum capacity. The presentation states that effluent currently covers about 200 ha.[29]In 2019, SEMC presented dewater rates from the mine were 31.76 GL/pa, with 30.8GL/pa discharged to the Gorrano Effluent Pond 26km to the south. A quick estimation of water cover at Gorrano suggests that on 9 May 2020 (the latest Google Earth photo), the area covered by water was just 140 ha. Indeed, the historic photo for 25 April, 2018 shows the Gorrano Effluent Pond covering just 94 ha.

The Engro/SECMC presentation suggests that at 200 hectare of water coverage the Gorrano Effluent Pond was at 35 percent capacity (10.5GL) in September 2018.

Figure 6: Gorrano Pond site 10/2016

Figure 7: Gorrano Effluent Pond 28/10/17 – 72.6ha



29 Syed Abul Fazal Rizvi, 2018.

Figure 8: Goranno Effluent Pond – 25/4/2018 - 94ha

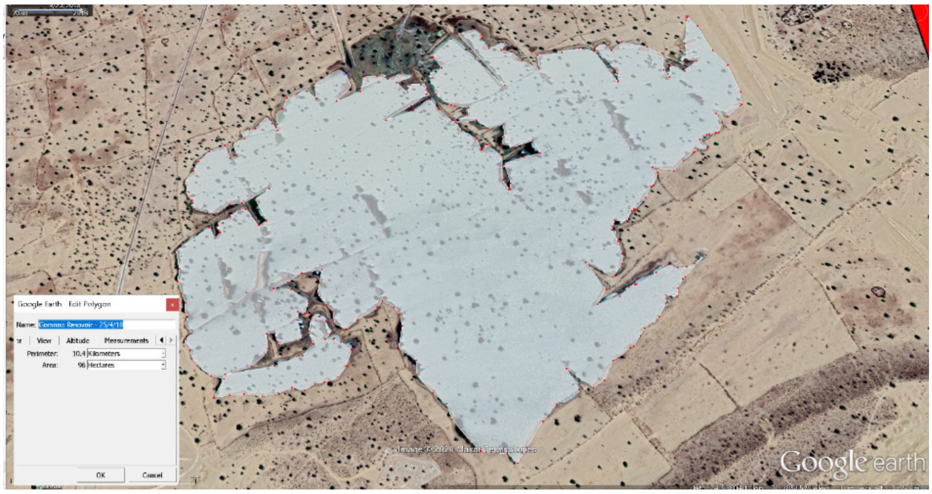


Figure 9: Goranno Effluent Pond – 139ha

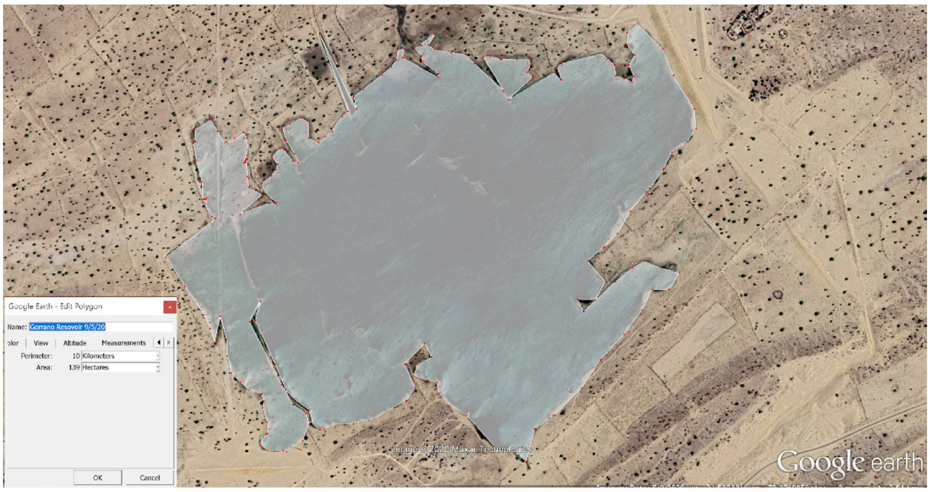


Figure 10: Block II Mine progress 9 May 2020

Net evaporation rates in the order of 1700mm/pa would mean the 200 ha area inundated by mine effluent at Gorrano is losing about 2.4 GLpa. With evaporation, this equates to about 8 GL (plus infiltration) discharged to Gorrano from Block 2 mine dewatering. With 3.4 GLpa suggested by SEMC for dust suppression, local irrigation, and potable use (after RO), and buffer pond, Block 2 mine has dewatered about 12 GLpa plus infiltration. Infiltration rates may be high in the area, but 20 GLpa across a 200 ha is extreme. Nevertheless, based on the Google Earth images above, the Gorrano Effluent Pond covers half of the area stated by SECMC/ Engro.

Our analysis suggests there is a significant over-estimation of Block II mine dewatering volumes. That SEMC/Engro overstate the Gorrano Pond levels by such a large margin is of serious concern for the projects and the Thari people. Clearly, their model predictions are inaccurate.

Power plant water demand

The 2010 Sindh Government Information Memorandum for Thar Blocks stated that "...groundwater could yield only limited supply for the short run and reliability," and questioned the plan to establish costly desalination facility without proven reliability.[30] Indeed, Oracle's 2011 Bible of Transaction documents for its Alternative Investment Market (AIM) admissions to the London Stock Exchange identifies that "sufficient volumes of Thar groundwater have not been established and that the volume of available groundwater may be insufficient for the power plant".[31]

Due to the high temperatures of Thar, a wet closed-cycle cooling system with natural draft cooling towers which limits power station water use is being installed. Although cooling towers withdraw less water than once through cooling, actual consumption is higher, as make-up water is needed to replace that lost through evaporation.[32] In the USA, average make-up water consumption usage is 2139 m3/GWh for sub critical, 1915 m3/GWh for supercritical, and 1590 m3/GWh for ultra supercritical plants.[33]

Three ESIAs provide estimates of raw water required for power plant operation;

- Engro: 21 GLpa,
- TEL: 9.64 GLpa,
- Oracle: 15.4 GLpa.[34]

Oracle's chief executive recently announced that instead of two stages of 660MW, the full 1,320MW will be constructed in phase 1,[35] which would double raw water demand estimates.

SECMC/Engro suggest that for a 330 MW Coal Fired Power Plant in Thar, 7.8 GLpa (8.75 cusecs) of treated water from 15.6 GLpa of raw water is required.[36] This is 31.2 GLpa for its 660 MW plant. Applying these estimates to the Thar plants' capacity, the total raw water demand is about 200 GLpa.

Due to the high salinity and hardness of available groundwater, desalination will be required to maintain adequate thermal exchange and reduce the build-up of scale on the metal surfaces of the cooling system. Reverse Osmosis (RO) typically recovers less than 50 percent of the raw water treated.[37] Twice the volume would therefore need to be treated, and half of that volume, with twice its original salinity and trace elements concentrations will have to be discarded.[38]

Published Water Consumption Factors (WCF) for wet cooling tower coal plants in Turkey is 2,600 m3/GWh.[39] The Thar Desert has a lower relative humidity than Turkey and therefore a higher evaporation rate. The WCF used by JICA for the Thar power plants with wet cooling towers is 3000m3/GWh.[40]

Based on JICA's estimated WCF, at 50 percent plant load about 56 GLpa of treated water will be required for the six power plants proposed on the Thar coal field. With an additional 50 percent reject brine from RO and

30 GoS, 2010.
31 Oracle Coalfields, 2011.
32 Maulbetsch, 2003
33 Carpenter, 2017.
34 Phase 1 instillation of 660MW. Oracle have announced an intention to now install 1320MW in Phase 1.
35 John Cornford, 2020.
36 SEMC & Engro, 2018.
37 SEMC & Engro, 2018.
38 Atab et al, 2016.
39 Balkess, 2017
40 JICA, 2013.

treatment, and an additional 6 percent of raw water for ash transport, dust suppression etc, the total volumes of raw water for a 50 percent plant load, will be about 120 GLpa. During peak generation (100% load), total raw water demand of the six plants rises to 240 GLpa. A plant load of 75 percent would see a raw water demand of 180GLpa for the six proposed Thar plants.

Total raw water demand for the Thar Coalfield must also include the water demands of the three mines, and indeed those of the local population, whose water supply has been removed. The raw water demand estimated in the ESIA for Block II is about 2.2 GLpa (6.6 GLpa for the three mines). Currently, about 1.5 GLpa of raw water is being used to produce desalinated drinking water for the local population of Block II (4.5 GLpa for the three mines).

The additional 11 GLpa for mine use and drinking water for the local population puts the estimated raw water demand for the six power plants running at 50 percent load is about 130 GLpa, 75 percent load is 190 GLpa, and 100 percent 250 GLpa.

See Table 6 for ESIA, SECMS/Engro (2018), and our estimates based on JICA (2013) of power plant water demand.

Table 6: Estimated water demand of Thar Coalfield power plants

Plant	Capacity (MW)	GWh 100% load	50% Plant load			75% Plant load			100% Plant load			Est.SECMS/Engro		ESIA
			Plant treated water (GLpa)	Plant raw water (GLpa)	Total raw water (GLpa)	Plant treated water (GLpa)	Plant raw water (GLpa)	Total raw water (GLpa)	Plant treated water (GLpa)	Plant raw water (GLpa)	Total raw water (GLpa)	Plant treated water (GLpa)	Plant raw water (GLpa)	Total raw water (GLpa) Est.
Thar SSRL	**1320**	**11563**	17.3	35	**37**	26	52	**55**	35	69	**74**	31	**63**	**42**
Engro	**660**	**5782**	9	17	**18**	13	26	**28**	17	35	**37**	16	**31**	**21**
TEL	**330**	**2891**	4.3	9	**9**	7	13	**14**	9	17	**18**	8	**16**	**10**
Siddiqsons	**330**	**2891**	4.3	9	**9**	7	13	**14**	9	17	**18**	8	**16**	**10**
ThalNova	**330**	**2891**	4.3	9	**9**	7	13	**14**	9	17	**18**	8	**16**	**10**
Oracle	**1320**	**11563**	17.3	35	**37**	26	52	**55**	35	69	**74**	31	**63**	**15**
TOTALS	**4290**	**37580**	**56**	**113**	**120**	**85**	**169**	**179**	**113**	**225**	**239**	**102**	**203**	**107**

Figure 11: Estimates by SECMC/Engro of power plant water demand

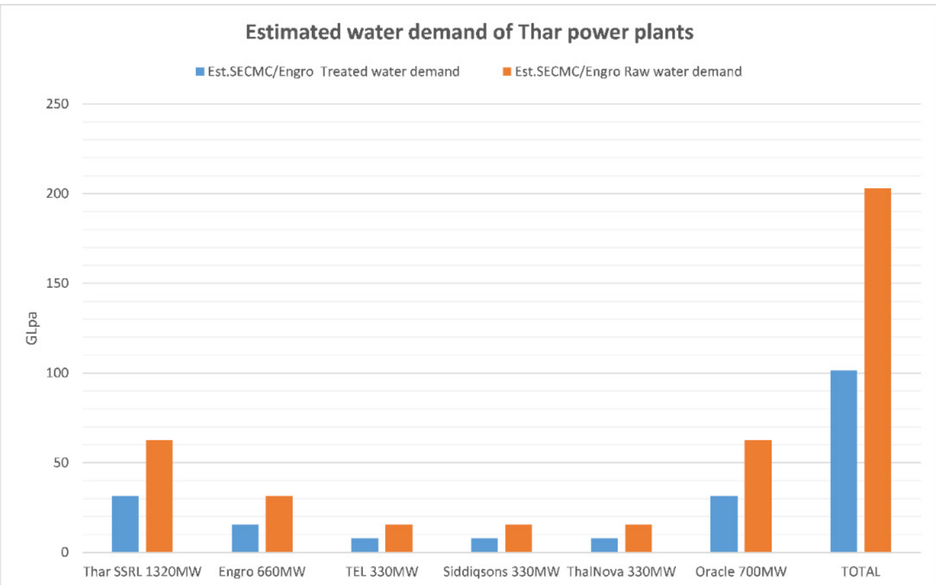
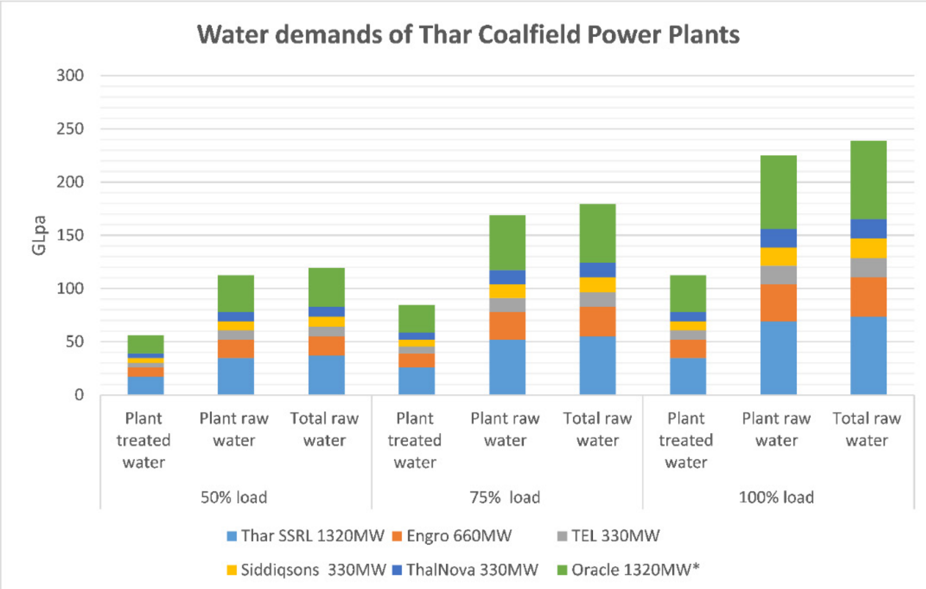


Figure 12: Estimates water demand of Thar Coalfield power plants



These estimates indicate that mine water cannot supply adequate supplies of water for the 4.3 GW of power plant capacity proposed for the Thar Coalfields. Whether additional groundwater abstraction is possible while mining and dewatering is occurring is questionable, as aquifer drawdown will add significantly to the depth of the bores required to abstraction any additional volumes, which will in turn increase drawdown. Mining and dewatering will also likely significantly affect groundwater behavior, which may not become apparent until concurrent mining occurs.

Table 7: Thar water Consumption for wet cooling towers (Table 2.5.4 taken from JICA, 2013)

Table 2.5-4 Assumption of Tariff of Generation (1,000 MW Class)

	Fuel (Coal) a	Water b	Val. O & M c	EPP d = a+b+c	CPP e	Tariff f = d+e/0.6
1st to 10th years	*4.932*	*0.212*	*0.205*	5.349	4.262	**12.452**
11th to 30th years	*4.932*	*0.212*	*0.205*	5.349	2.173	**8.971**

Fuel (Coal)

1. Heating Value (Block II): 3,211 kcal/kg, 12,742 Btu/kg (0.252 kcal/Btu)
2. Price of coal: case 1=US$50/ton, case 2= US$55/ton and case 3=US$60/ton
3. EPC cost: US$1,500 mil. for 1,000MW (US$1,500/kW)
4. Net thermal efficiency: 37%
5. Heat rate: 9,222 Btu/kW (3,412 Btu/kWh divided by 37%)
6. Coal cost per kW
   - Case 1: US$50/1,000 x (9,222/12,724)= US¢3.62/kWh (Rs.4.114/kWh) -Rs.0.818 to Case 3
   - Case 2: US$55/1,000 x (9,222/12,724)= US¢3.98/kWh (Rs.4.523/kWh) -Rs. 0.409 to Case 3
   - Case 3: US$60/1,000 x (9,222/12,724)= US¢43.4/kWh (Rs.4.932/kWh) applied to assumption

Water Charge

1. Water consumption for wet cooling: 3 t/MWh ⇒3 L/kWh (general information)
2. Cost of water: Rs.70.5/ton ⇒Rs.0.0705/L (please refer to Clause 5.2 Water Supply)
3. Cost of water per kWh: 3 x 0.0705 = Rs.0.212/kWh

Valuable O & M

Rs.0.1708 x US$1,500 mil./US$1,250 mil. = 0.1708 x 1.2 = Rs.0.2050

CPP

1. 1st to 10th years: Rs.3.5515 x US$1,500 mil./1,250 mil. = Rs.3.5515 x 1.2 = Rs.4.262
2. 11th to 30th years: Rs.1.8109 x US$1,500 mil./1,250 mil. = Rs.1.8109 x 1.2 = Rs.2.173

Source: Prepared by the JICA Survey Team

Thar Coalfield water balance estimates

Even based on proponent's model predictions there is insufficient mine water available for the Thar power projects. Mine dewatering estimates suggest substantial deficits in water demand for the power projects which worsen after peak mine inflows of around 83 GLpa at mining year 5, declining to about 45 GLpa at mining year 25. Raw water use by the mines would be about 6.6 Glpa, leaving just 76 GLpa at mining year 5, 53 GLpa at year 15, and just 38 GLpa at mining year 25. See Table 8.

Table 8: Raw water deficits for Thar Coalfield

Mine water (GLpa)				Raw water demand (GLpa)			Deficit (GLpa)
Mining year	**Mine dewatering**	**Mine demand**	**Mine raw water supply**	**Power plants 75% load**	**Local population**	**Total**	
5	83	6.6	**76**	180	4.5	**185**	**-108**
15	60		**53**				**-131**
25	45		**38**				**-146**

The raw water demand of the six power plants (4.29 GW) proposed for the Thar Coalfields is about 180GLpa (75% load). With a further 4.5 GLpa of raw water for local population use, total raw water demand is about 185 GLpa. Raw water deficits, without surface water/effluent diversions, at peak mine dewatering (year 5) are about 108 GLpa, increasing to 146 GLpa at mining year 25.

While the Sindh Government has proposed to implement a Left Bank Outfall Drain (LBOD) diversion of about 33 GLpa, this is yet to eventuate and may result in a much smaller volume due to treatment costs. Power companies are already being asked to assist with funding for water diversion and treatment projects.

The second surface water diversion proposed by the Sindh Government is from the Makhi Farsh Link Canal. The intake from the Dhoro Escape is for a maximum of 40 GLpa raw water. Storage evaporation losses will reduce this to 36 GLpa.

Adequate cooling water is a limiting factor for thermal power plant operations. The risks for Pakistan are great, and have the potential for creating circular debt due to large capacity payments for thermal power plants that cannot hope to operate at full capacity based on available local water resources.

Thermal power generation on the Thar Coalfields must be reevaluated. Either significant impacts will be inflicted on irrigation and food production in the Sindh, or installed power generation capacity will need to be substantially reduced.

Water diversions

To incentivise private development of coal based projects, the Pakistan and Sindh governments have underwritten and guaranteed a number of underlying risks and costs of the development of the Thar Coalfield projects, including infrastructure and water supply systems.[41] The government of Sindh is temporarily providing water to the Thar coal fields through the Naukot-Mithi pipeline.[42] Plans to supply the Thar projects with irrigation water from the IBIS, as well as expensive treated saline effluent, may have long-term consequences that have not yet been fully evaluated.

The IUCN EIA Guidance for Coal Fired Power Plants in Pakistan warns that “the demand for large quantities of water for cooling purposes needs to be managed taking into account previous water uses and its multiple users.”[43] None of the ESIAs prepared to date, or indeed those for water diversions by the Sindh Government have considered the impacts of withdrawing large volumes of water from the Indus Basin Irrigation Scheme (IBIS).

Pakistan is ranked third in the world in facing severe water shortages. It has been estimated that by 2025, there will be very little or no clean water available in the country. Droughts are common and their frequency and severity has been increasing. Diverting any IBIS water to Tharparkar should be opposed by Sindh irrigators and municipal water authorities.

There are also issues of whether the aging infrastructure of the IBIS can reliably supply critical Thermal power cooling water. The 2017 Irrigation Management Strategy for Irrigated Agriculture of Sindh Province[44] declares that:

All three barrages in Sindh, that divert water from the Indus River into the main canals, are 60-80 years old;

Most of the canal infrastructure including water control gates and mechanical movements are more than 60 years old, and many are not functional;

The canal infrastructure has been operated at capacities much higher than designed, which has led to serious structural deterioration at all levels of the canal network.

Within the canal network, there is no storage capability and all water diverted from the river must flow through the canal network, eventually arriving at the farm. [45]

Funding for irrigation authorities in Sindh in 2009 was just USD45 million, of which only 17 percent was spent on maintaining canals and flood mitigation infrastructure: 40 percent on administration, and 43 percent for electricity charges for tube wells operation.

Executive engineers are under considerable political interference, with routine operational issues taking up most of their time, leaving little for professional water resource management.

41 Private Power and Infrastructure Board, 2008.

42 The third pole, 2020.

43 Coutinho et al, 2014.

44 GoS, 2017.

45 GoS, 2017.

Figure 13: Lower Indus Basin Irrigation System, LBOD, and Thar Blocks

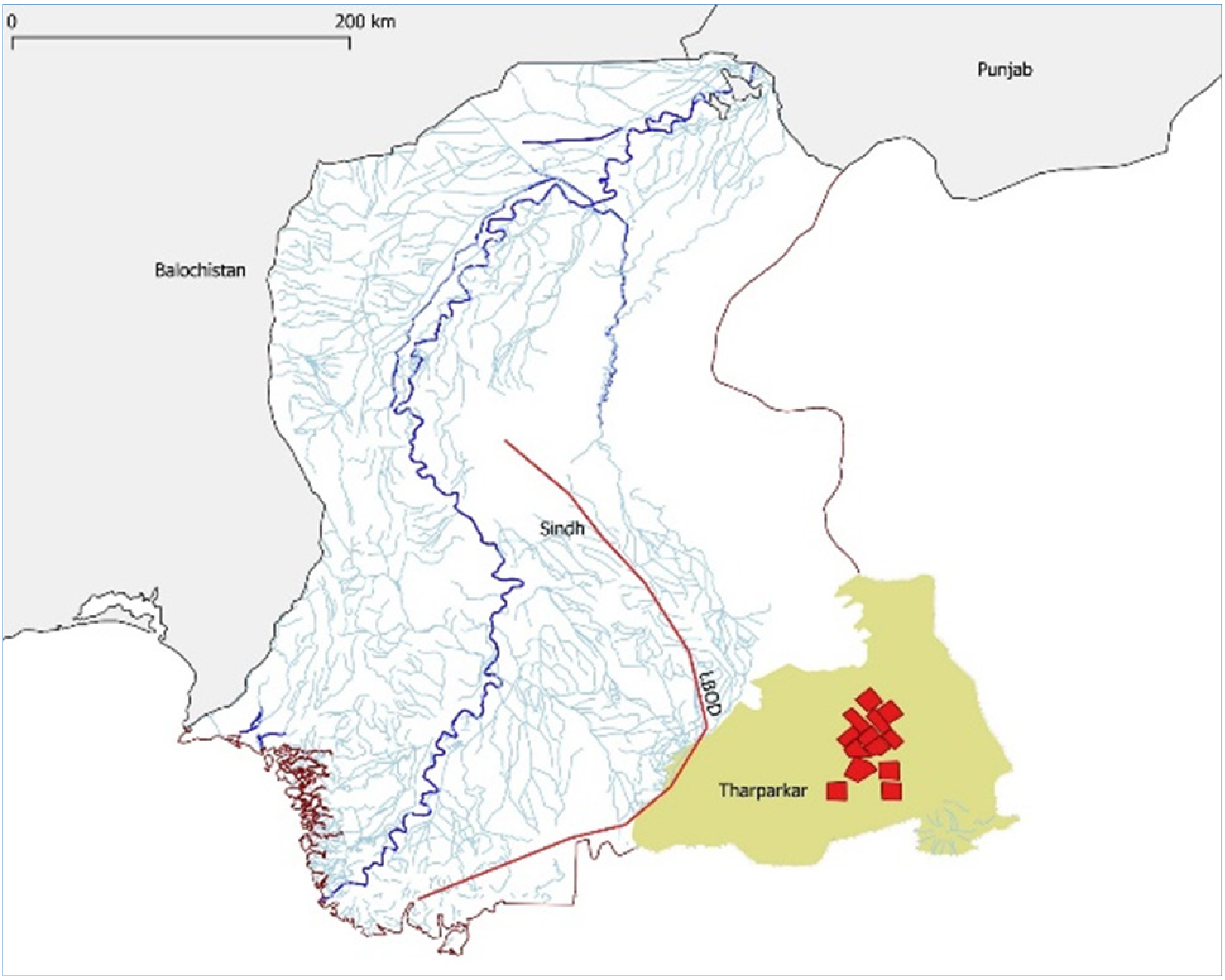
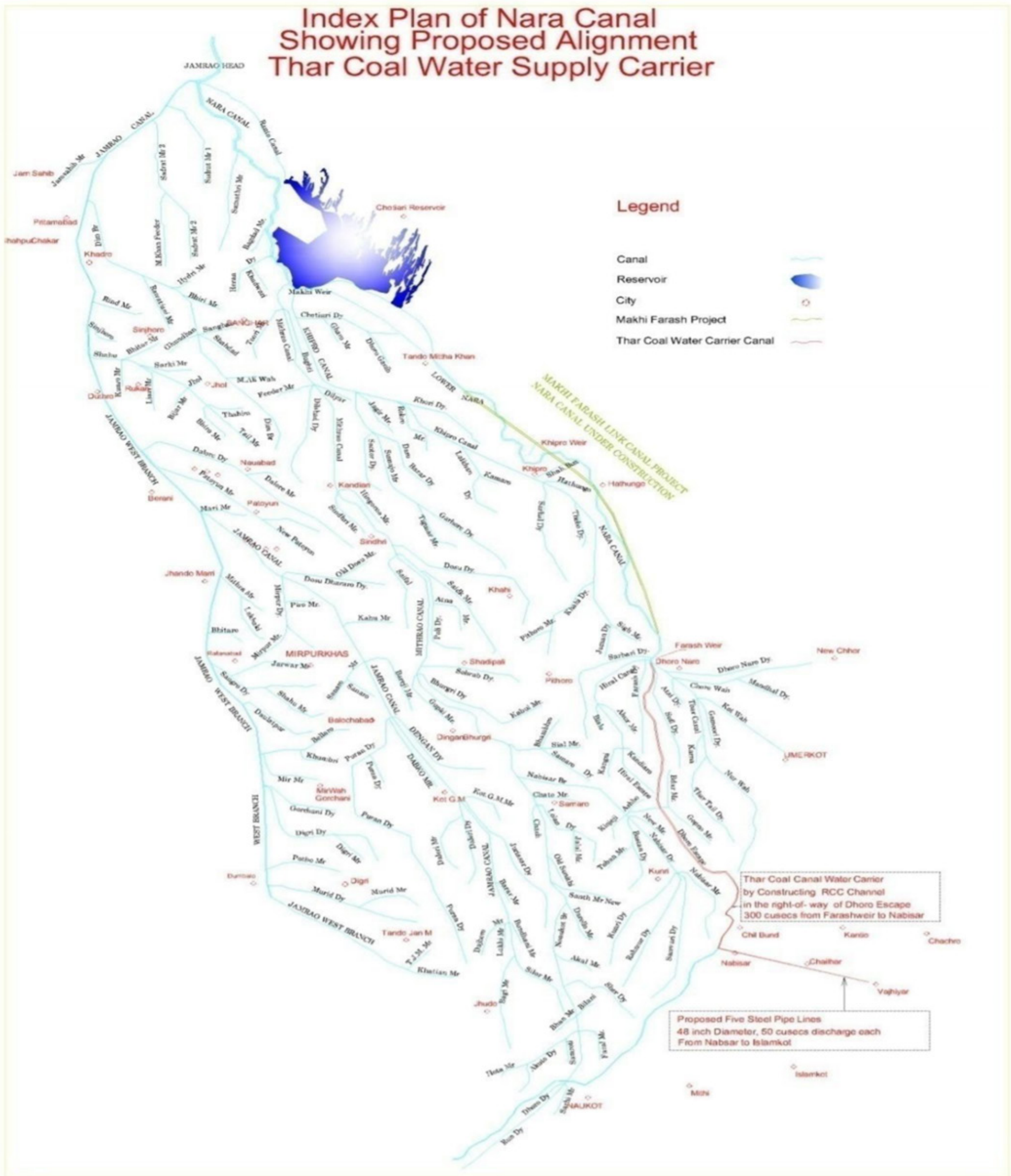


Figure 14: Index Plan of Nara Canal showing proposed Thar Coalfield offtake



The Sindh Government has a track record for poorly managed water projects, which are characterised by inefficiencies, completion delays and time and cost overruns. For successful implementation of highly secure water for thermal plant cooling, the Sindh Government requires significantly more asset management ability than it has shown to date.[46] However, should the Sindh Government manage to secure IBIS sufficient water for the Thar coal projects, it will be at the expense of irrigated agriculture. No assessment has been undertaken into the impacts on farming communities and industries that rely on water proposed to be diverted to the Thar projects.

Pakistan's National Water Policy expressly sets out the relative priority of water use:

1. Drinking and Sanitation
2. Irrigation including land reclamation
3. Livestock, fisheries and wildlife
4. Hydropower
5. Industry and mining
6. Environment, river system, wetlands, aquatic life
7. Forestry including social forestry
8. Recreation and sports
9. Navigation [47]

Irrigation will be affected by diverting water from the IBIS to the Thar Coalfields, in contravention of the National Water Policy.

Nara Canal diversion to Nabisar and Vajhair Reservoirs

The Sindh Government is in the process of providing infrastructure to supply Block-I power plant with water from Nara Canal to the site of power plant. This diversion will supply 40 GLpa from a new 3.3 GL reservoir at Vaihair.[48] Funding of USD67 million for the Makhi Farsh Link Canal Project, part of the Thar Water Supply Project, has been approved on 50/50 cost sharing basis between the Sindh and Pakistan Governments.[49] The Sindh Government has already spent USD12 million on the project with significant additional funding yet to be allocated by Sindh and Federal Governments for completion of the scheme.[50]

The project will supply fresh water to Nabisar, in Tharparkar from the Farash Complex near Dhoro Naro, in the District of Umerkot. Specifically the project proposes:

- 178.6 GLpa to Nabisar Thar from Farash Complex near Dhoro Naro, district Umarkot.
- Intake 40 GLpa raw water from Dhoro Escape from Makhi-Farash Canal to Nabisar
- Reservoir to store 45 days of water (5 GL) at NabisarTreatment plant to make it suitable as per the requirements of the Government of Sindh
- Build Pumping Station and 60.71 Km Pipeline to transfer water to Nabisar
- Pipeline for transmission of water from Nabisar Reservoir to Vajhair
- Reservoir for 30 Days Storage (3.3 GL.pa capacity) at Vajhair.

46 Briscoe, et al, 2005.
47 GoP, 2018.
48 Enertech Water Private Limited, 2020.
49 Habib Khan Ghori, 2019.
50 PPI, 2019.

As of April 2019, most of this work was incomplete, including:

- 30 percent of canal realignment,
- 60 perccent of minor canals.
- 60 percent of cross regulators,
- 50 percent of bridges,
- 92 percent of culverts were incomplete.[51]

While a maximum flow of 174GLpa of IBIS water will be diverted, the intake at Dhoro Escape from Makhi-Farash Canal to Nabisar is only 40GLpa.

An issue for water security is the extreme evaporation rates of the Thar dessert (net 1700mm/pa)[52]which will see any surface water storage experience significant losses. This makes large shallow storages impractical. Evaporation of the reservoir at Vaihair would see the 83 hectare reservoir lose over 1.5 GLpa. The 100 ha Nabisar Reservoir would lose about 1.7 GLpa to evaporation.

Therefore, evaporation losses from the 40 GLpa flow to Nabisar would be about 8 percent.

The Sindh Irrigation and Drainage Authority suggests salinity (TDS) of the Chotiari Reservoir, which would reflect the Nara Canal water,[53]is within Thermal power plant parameters (<500mg/l). However, Total Suspended Solids, BOD, COD, oil and grease are above the National Environmental Quality Standards and would likely need water treatment. Reject water percentages would be low in comparison to RO treatment.

The transfer of a maximum flow of 174 GLpa from irrigation use will have a devastating impact on agricultural production reliant on the Makhi-Farash Canal . The Makhi-Farash link canal was constructed in 2009 to increase the cropping intensity in Sindh from 75 per cent to 148 per cent, and irrigate 120,000 ha in the drought-affected districts of Sanghar and Mirpurkhas.[54]The proposal intends to draw almost 8% of the capacity of the Canal at Farash. The same volume needed to irrigate 9,000 hectares of farmland in Sanghar and Mirpurkhas.

Diversion from Left Bank Outfall Drain

The Left Bank Outfall Drain (LBOD) was built in the 1980s/90s with a USD1bn World Bank loan with the intention of controlling saline groundwater intrusion of over half a million hectares of over-irrigated land in the lower Indus River Plain.[55] The flow of the LBOD is, however, very low compared to its anticipated capacity with much of its infrastructure damaged and inoperable. Many of the scavenger wells operate at only 30% efficiency.[56]

Described as social and ecological disaster,[57] the LBOD is a not a reliable source of thermal power cooling water. Treatment costs will be high as LBOD effluent is highly contaminated with sugar mill discharge and other industrial waste, urban and domestic sewage, and agricultural effluents such as fertilizers and pesticides.[58] LBOD effluent is also highly saline (up to 23,000 mg/l), and contains significant concentrations of sulphur dioxide, hydrochloric acid, lead, grease and oil,[59] low pH and dissolved oxygen, and high sodium, calcium, magnesium, and calcium carbonate.[60]

A 2011, Sindh Irrigation and Drainage Authority identified a diversion from the LBOD to the Thar Coalfields was not feasible due to very high salt content in the water combined with the high pumping

51 PPI, 2019.
52 Geyh et al, 2008.
53 GoP, 2012.
54 The News International, 2006.
55 World Bank. 1998.
56 Zardari et al, 2016.
57 South Asia Citizens Web, 2008.
58 Mahessar 2017.
59 Qureshi, 2015.
60 Mahessar, 2016.

cost.[61] However, Oracle's 2017 power plant ESIA identifies the commitment by the Government of Sindh to construct an alternative water supply from the LBOD at Nabissar, along with a large RO plant and lined reservoir, and is linking this with the Thar Coalfield via a pipeline to Vejihar where a further large lined reservoir has been constructed. The total supply capacity of this scheme was to be approximately 3,100 L/s (98 GLpa) for individual block holders to apply for a water supply agreement to allow them to access the reservoir at Vejihar and pipe water to their block.

However, the scheme being undertaken by the Sindh Government is for just 31 GLpa of effluent supply from the LBOD. Under the scheme a channel from LBOD to Nabisar and water treatment plant are being constructed. A 56km pipeline from Vajihar to the Thar Coalfield has been laid. The State's Chief Minister revealed the cost constraints on Government expenditure by directing the Energy Minister to "talk to the private companies working in Thar Coal to share and shoulder some of the expenditures for completion of the scheme."[62]

The Sindh Government plans to pump LBOD effluent to the 5 GL storage pond at Nabisar, where it will undergo pre-treatment through a Membrane Bio Reactor (MBR) filtration facility planned at a cost of USD85 million and a maximum inflow of just 2.3 GLpa.[63] The water must be pre-treatment to make it fit for further treatment by Reverse Osmosis (RO) Plant, also at Nabisar, and then pumped to the power plant.

Due to the poor reliably of LBOD infrastructure and the high cost of treating LBOD effluent before it can be desalinated, the likelihood of the LBOD supplying significant volumes of treated water for Thar power plants is low.

61 GoS, 2011.

62 PPI, 2019.

63 Business Recorder, 2019.

Impacts on agriculture

Pakistan is extraordinarily dependent on its water infrastructure. The Indus Basin Irrigation System (IBIS) is one of the largest irrigation systems in the world comprising three major reservoirs with a design capacity of about 20,000 GL which irrigates about 17 million ha[64](80% of all arable land), and produces 90% of the Country's food and fibre.[65] However, the system is subject to a number of issues such as sediments in reservoirs and overall low system efficiency coupled with a population growth of over 2%, as well as, increased urbanisation and industrialisation.[66]

Due to a combination of age and what has aptly been called the "Build/Neglect/Rebuild" philosophy of public works, much of the infrastructure is crumbling. This is true even for some of the major barrages, which serve millions of hectares and where failure would be catastrophic. There is no modern Asset Management Plan for any of the major infrastructure.[67]

A 2012 report for the World Bank suggested that "... implementation of water sector projects in Pakistan is characterised by inefficiencies, completion delays and time and cost overruns. Factors that affect implementation include: weak implementation planning and management, litigation related to land acquisition, non-compliance with agreed resettlement and rehabilitation programs, lack of attention to environmental issues, delays in procurement, delays in preparation of accounts and audits, and lack of preparation for the transition from construction to operations."[68]

Nevertheless, irrigated agriculture is the largest sector of Pakistan's economy contributing about 24 percent of Gross Domestic Product (GDP), half of employed labour force, and three quarters of foreign exchange earnings.[69]

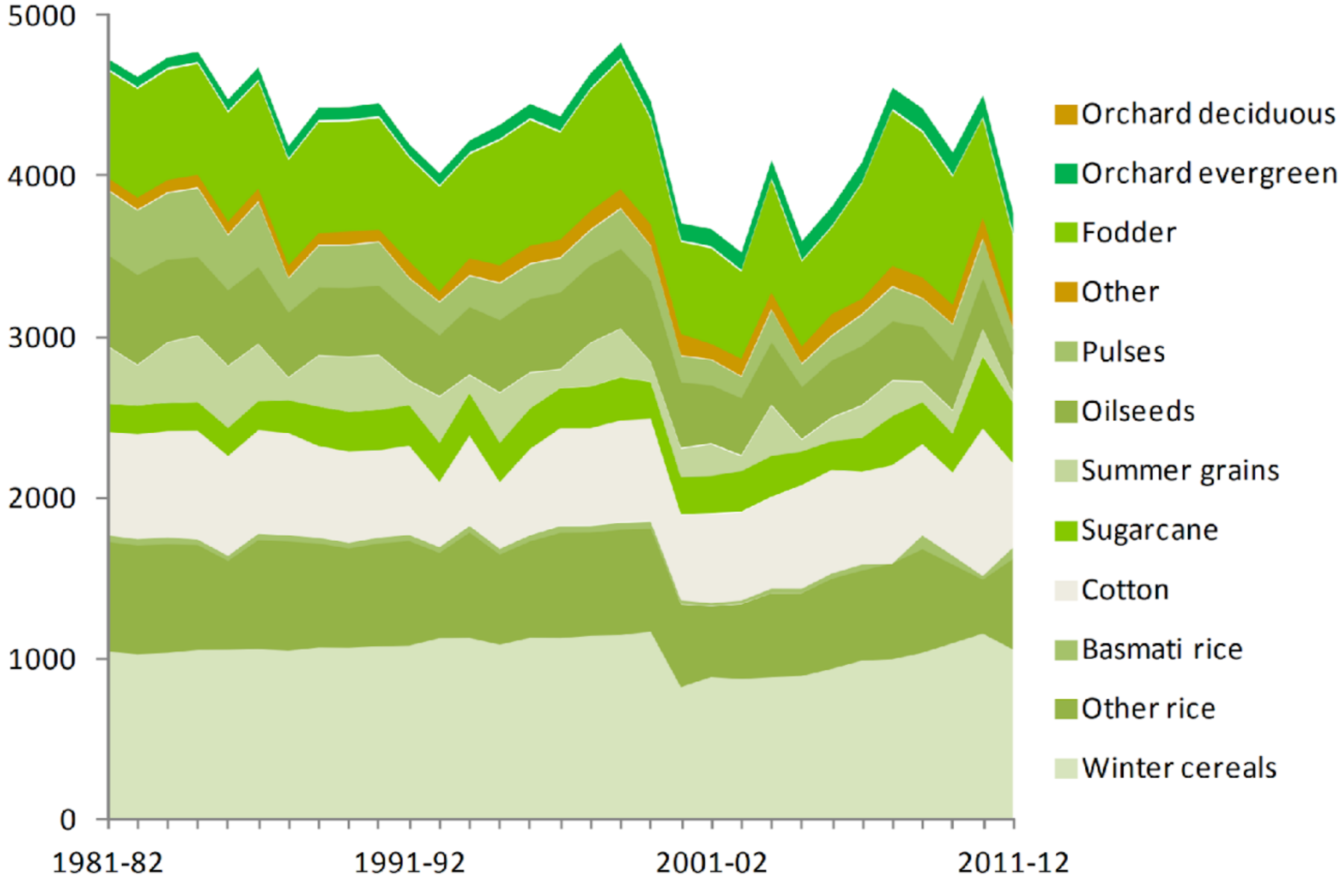
With 14 canal commands and 5 million ha of irrigated agriculture, Sindh province is the second biggest beneficiary of the IBIS after Punjab. However, the sector suffers from low water productivity, due to water seepage from degraded infrastructure, inadequate irrigation and cropping practices, and inadequate water distribution.[70]

Actual main canal abstractions are generally much higher than their design allocations. The Nara Canal, from which Thar water diversions are planned, has a design allocation of 6,100 GL but estimated withdraws in 2016 were between 7,400 to 10,000 GL.[71]These figures may be grossly underestimated. The 2010 Sindh Water Resources Development and Management Investment Programme prepared for the Asian Development Bank, includes a survey of 147 Sindh Diversion Outlets that were drawing four times more water than they were allowed to draw. One DO was drawing over 30 times its approved quantity.[72]Withdrawals from 55 Diversion Outlets on the Nasir Brach Canal, from which Thar water will be drawn, was almost 3 times more than the designed.[73]

Irrigation in Sindh Province has been in decline over the past decade. In 2012, total river diversions were estimated at 60,000 GL. (FoDP, 2012). In 2017/18, total withdrawals were down to 50,700 GL, a reduction of 12 percent

64 Soomro et al, 2018.
65 Ashraf, 2015.
66 Ashraf, 2016.
67 Briscoe et al, 2005.
68 Briscoe et al, 2005.
69 GoP, 2020.
70 AHT Group, 2010.
71 GoS,, 2017.
72 AHT GROUP AG, 2010.
73 AHT GROUP AG, 2010.

Figure 15: Sindh area of crop groups in 1000s ha 1981 to 2012. (Taken from Mac Kirby & Mobin-ud-Din Ahmad, 20160



The heavy dependence of the Pakistan economy on agriculture renders it vulnerable to adverse weather conditions and other natural factors which affect agricultural yield.

According to the International Monetary Fund (IMF), Pakistan is ranked third among the countries facing severe water shortage.[74]In May 2018, the Pakistan Council of Research in Water Resources (PCRWR) announced that by 2025, there will be very little or no clean water available in the country. Per capita surface water availability has declined from 5,260 cubic meters per year in 1951 to around 1,000 cubic meters in 2016, and is predicted to drop to about 860 cubic meters by 2025 marking Pakistan a "water scarce" country.[75] A recent Government Economic Survey identified that: “Erratic weather patterns and climate change have emerged as the biggest environmental challenge… with major impacts on agricultural productivity…In the absence of a change in management practices and technology, an overall reduction will be registered for all cereal crop yields.” [76]

Statistical analysis of weather recorded over the past 36 years has found temperatures of summer days and tropical nights has increased in the Sindh with overall significant warming trends for monthly maximum temperature as well as for warm days and nights reflecting drying conditions.[77] The number of wet days, the number of very heavy precipitation days, very wet and extremely wet day, and daily rain intensity all showed a decrease.[78] This is reflected in the 2017/18 Sindh non-monsoon cropping season when water availability was 33.5 percent less than the normal availability.[79]

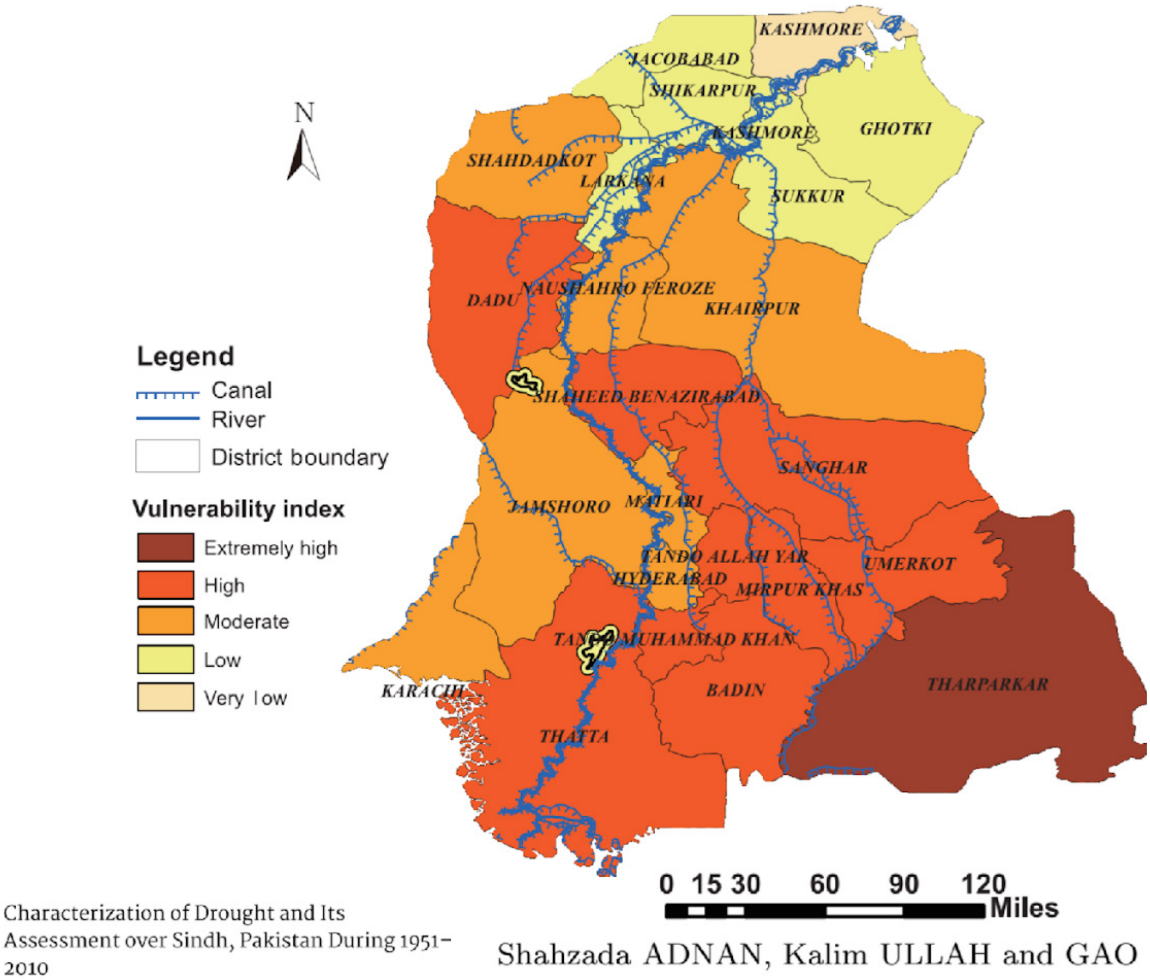
74 Nabi et al, 2019; Kalpana et al, 2015.
75 GoP, 2018.
76 Gop, 2019.
77 Abbas et al, 2018.
78 Abbas et al, 2018.
79 GoP, 2019

Drought and drought like conditions have been prevailing in Sindh since 2013. Drought has been a recurring phenomenon in of the Province. Monsoons tend to fail after every four to six years, and drought period may last two to three years. Indeed, major droughts were experienced in Sindh in 1951–1956, 1962–1963, 1968–1969, 1979–1981, 1985–1988, and several in the 1990s and 2000s, [80] with severe droughts experienced in 1969, 1974, 1987 and 2002 (See Figure 16: Sindh Districts Drought Vulnerability Index). [81]

The 2019 Sindh Drought Needs Assessment[82]identifies the incidence of poverty in Sindh at 44%, and undernourishment at 22%.[83]In 2017, a food security assessment for Tharparkar, Umerkot, Sanghar and Jamshoro Districts found high livestock losses, inadequacy of own produced cereals, high malnutrition among children under the age of 5 and pregnant and lactating women, problems in accessing health care facilities/providers, poor housing status, poor access to improved water sources and sanitation, and very high food insecurity.[84]

Any withdrawals from the Indus Irrigation Scheme for thermal power generation is likely to have a devastating impact on food security, particularly during drought.

Figure 16: Sindh District drought vulnerability Index 1951 -2010 (Taken from Natural Disaster Consortium, 2019)



Supplying Thermal power generation with desperately needed irrigation water supplies has profound risks for food security and will have an impact food and fiber industries that underpin the Sindh's economy.

80 Hagler Bailly 2013.

81 Natural Disaster Consortium, 2019.

82 Natural Disasters Consortium (NDC), 2019.

83 Natural Disaster Consortium, 2019.

84 Pakistan Food Security Cluster (FSC), 2017.

Conclusion

The proposed Thar power projects cannot be adequately supplied with locally sourced groundwater. Raw water deficits based on ESIA model predictions of peak mine dewatering are about 108 GLpa, increasing to 146 GLpa after 25 years of mining. However, we believe these predictions may significantly overestimate the volumes of groundwater available from mine dewatering.

While the financial risks associated with building thermal coal plants in the Thar Desert are enormous for Pakistan and the project proponents, there are severe social risks for the 1.65 million Thari people who depend on the groundwater resources of the District. Mining induced aquifer drawdown will effectively remove the sole permanent water supply for many of these people, who will be left relying on treated water supplied by mining and power companies. There is a very real risk that aquifer drawdown will extend into Gujerat India and impact communities there. Mining will also result in a substantial reduction in groundwater feeding the Ramsar listed Rann of Kutch and its communities.

While diversions from the Indus Basin Irrigation Scheme (IBIS) are proposed to improve water security for power projects, the water is being used for irrigation in drought-affected Districts. Despite these impacts, reliability will be poor, as much of the infrastructure supporting the IBIS is old and neglected.

As competition for water increases in Pakistan, so too will conflicts. The intensity of conflicts over water have become more severe, and will likely increase in line with population, climatic changes, and more dependency on declining water resources.[85]

Constraints in water availability is a widespread and growing vulnerability for the power generation industry.[86]Water insecurity risks plant closures or reduced plant load which erodes plant profitability.[87]

As large surface water diversions from the IBIS will significantly disrupt existing irrigation, with the potential for political tensions and social unrest,[88]further development of the Thar coal project poses significant financial and social risk.

Thermal power generation on the Thar Coalfields must be reevaluated. Either devastating impacts will need to be forced onto irrigation and food and fibre production in the Sindh, or significant power generation capacity needs to be cut from current plans.

85 Muhammad Atiq Ur Rehman Tariq et al, 2020 ,

86 Carpenter, 2017.

87 IEA, 2012.

88 Caldecott et al, 2015.

References

Abbas, F., Rehman, I., Adrees, M. *et al.* Prevailing trends of climatic extremes across Indus-Delta of Sindh-Pakistan. *Theor Appl Climatol* **131,** 1101–1117 (2018). https://doi.org/10.1007/s00704-016-2028-y

AHT Group, 2010a. Sindh Water Resources Development and Management Investment Programme (PPTA). https://www.aht-group.com/cms/index.php?id=239&L=0

AHT GROUP AG, 2010b. Sindh Irrigation and Power Department and Asian Development Bank Project Preparatory Technical Assistance to the Government of Sindh Islamic Republic of Pakistan FINAL REPORT. https://www.adb.org/sites/default/files/project-document/63468/41514-01-ind-tacr.pdf

Ali Asghar Mahessarl Kishan Chand Mukwana, Abdul Latif Qureshi, Muhammad Ehsan, Abdul Latif Manganhar, Jamshoro, 2016. Assessment of Water Quality of LBOD System and Environmental Concerns. *Quad-E-Awam University Research Journal Of Engineering, Science & Technology*, Volume 15, No.L , Jan-Jun 2016.

Ashraf M., 2015. *Promising land and water management practices: A manual*. International Center for Agricultural Research in the Dry Areas (ICARDA), Country Office Pakistan, pp, 85.

Ashraf M., 2016. Managing water scarcity in Pakistan: moving beyond rhetoric. *Proceedings of AASSA regional workshop, challenges in water security to meet the growing food requirement,* p. 2-14; Brisco J., U. Qamar (2006). Pakistan's water economy running dry. The World Bank. Oxford University Press, Karachi.

Atab, Mohanad & Smallbone, Andrew & Roskilly, Tony., 2016. An operational and economic study of a reverse osmosis desalination system for potable water and land irrigation. Desalination. 397. 174 - 184. https://doi.org/10.1016/j.desal.2016.06.020;. Desalination. 397. 174 - 184.

Balkess El-Khozondar, and Merih Aydınalp Koksal. 2017. Investigating the water consumption for electricity generation at Turkish power plants. E3S Web of Conferences 22, 00039 (2017) DOI: 10.1051/e3sconf/20172200039

Briscoe, J., U. Qamar, M. Contijoch, P. Amir, and D. Blackmore. 2005. “Pakistan’s Water Economy: Running Dry.” World Bank, Washington, D.C., and Islamabad. https://projects.iq.harvard.edu/files/johnbriscoe/files/7._briscoe_-_qamar-_pakistans_water_economy-running_dry-_oxford_univ_press_2007.pdf

Business Recorder, 2019. LBOD water for Thar coal: Murad calls for choosing between RO and MBR technology. 2 June, 2019.https://fp.brecorder.com/2019/06/20190602483258/

Carpenter, A M, 2017. Water conservation in coal-fired power plants. IEA Clean Coal Centre. https://usea.org/sites/default/files/Water%20conservation%20in%20coal%20fired%20power%20plants%20-%20ccc275.pdf

Coutinho, Miguel and Butt, Hamza K. 2014. *Environmental Impact Assessment Guidance for Coal FiredPower Plants in Pakistan.* Islamabad: IUCN Pakistan. 149 pp.

Caldecott, B., Dericks, B., and Mitchell, J., 2015. Stranded assets and subcritical coal: the risk to companies and investors. Oxford: Smith School of Enterprise and the Environment. https://www.smithschool.ox.ac.uk/research/sustainable-finance/publications/Stranded-Assets-and-Subcritical-Coal.pdf

CPEC - China Pakistan Economic Corridor, 2020. http://cpec.gov.pk/

Environmental Management Consultants, 2012. Environmental and Social Impact Assessment (ESIA) Coal Mining Project - Sinhar Vikian Varvai, Block- I .

Enertech Water Private Limited, 2020. DRAFT Owner's Engineer for Supply of Water from Nabisar to Vajhair. Environmental Impact Assessment (EIA).

Engro Powergen Thar (Pvt.) Limited, 2014. *Application for a Generation License of 2X330 MW Thar Coal Based Power Plant at Thar Block II Sindh*: To National Electric Power Regulatory Authority (NEPRA). 2/12/2014.

Farooq Choudry, MA, Yasmin Nurgis, Mughal Sharif, Amjad Ali Mahmood, Haq Nawaz Abbasi, 2010. Composition, Trace Element Contents and Major Ash Constituents of Thar Coal, Pakistan. *American Journal of Scientific Research* ISSN 1450-223X Issue 11(2010), pp.92-102.

Fassett, JE and Nazir A. Durrani, 1994. *Geology and Coal Resources of the Thar Coal Field, Sindh Province, Pakistan*. U.S. Geological Survey Open-File Report 1994.

Geyh, Mebus & Ploethner, D..,2008. *Origin of a fresh groundwater body in Cholistan, Thar Desert, Pakistan*. Geological Society, London, Special Publications. 288. 99-109. 10.1144/SP288.8. https://www.researchgate.net/publication/240675625_Origin_of_a_fresh_groundwater_body_in_Cholistan_Thar_Desert_Pakistan

Nabi, G., Ali, M., Khan, S. *et al.* The crisis of water shortage and pollution in Pakistan: risk to public health, biodiversity, and ecosystem. *Environ Sci Pollut Res* **26,** 10443–10445 (2019). https://doi.org/10.1007/s11356-019-04483-w:

Geyh, Mebus & Ploethner, D., 2008. Origin of a fresh groundwater body in Cholistan, Thar Desert, Pakistan. Geological Society, London, Special Publications. 288. 99-109. https://www.researchgate.net/publication/240675625_Origin_of_a_fresh_groundwater_body_in_Cholistan_Thar_Desert_Pakistan

GoP -Government of Pakistan, 2019. *Pakistan Economic Survey 2018-19.* http://www.finance.gov.pk/survey/chapters_19/Economic_Survey_2018_19.pdf

GoP - Government of Pakistan, 2020, *Agricultural Statistics*, Pakistan Bureau of Statistics. http://www.pbs.gov.pk/content/agriculture-statistics

GoP - Government of Pakistan, 2018. National Water Policy. http://mowr.gov.pk/wp-content/uploads/2018/06/National-Water-policy-2018-2.pdf

GoS -Government of Sindh, 2010. Information Memorandum Blocks – I, III-B, IV & VII, Thar Coal Fields District Tharparkar. Sindh Pakistan Coal and Energy Development Department., Government of Sindh. https://sedf.gos.pk/pdf/Information%20Memorandum%20for%20Thar%20blocks%202010.pdf

GoS -Sindh Irrigation and Drainage Authority, 2011. Preparation of Regional Plan for The Left Bank of Indus, Delta and Coastal Zone Phase - I Final Report. http://sida.org.pk/download/reports/1.Vol-I%20Main%20Report-%20Final_June_2011%20(revised).pdf

GoS -Sindh Irrigation and Drainage Authority, 2012. Water Sector Improvement Project Phase – I (WSIP-I) Preparation of Regional Plan for Left Bank of Indus Proposed Project on Rehabilitation of Deh Akro – II and Chotiari Wetland Complex. http://sida.org.pk/download/lbg/phaseIII/Phase.III.Feasibility.Dek%20Akro%20II.Chotiari.Wetland.GRK.FINAL.20.2012.PDF

GoS -Government of Sindh, 2017. The Irrigation Management Strategy for Irrigated Agriculture of Sindh Province (Pakistan). http://metameta.nl/wp-content/uploads/2017/11/170323_Fourth-Draft-Irrigation-Managment-Strategy-for-Irrigated-Agriculture-of-Sindh-Province-Pakistan.pdf

Habib Khan Ghori, 2019. Murad decries Centre for dropping 36 Sindh schemes of Rs51bn from PSDP. Published in Dawn May 29, 2019. https://www.dawn.com/news/1485130

Hagler Bailly, 2012.Thar Coal Block II Mining Project Environmental and Social Impact Assessment Final Report VOLUME 1 of 2. September 3, 2012. https://www.engroenergy.com/wp-content/uploads/2012/PDF/R2M03THP-Final_Report-ESIA_of_Thar_Coal_Block_II_Mining.pdf

Hagler Bailly, 2012.Thar Coal Block II Mining Project Environmental and Social Impact Assessment Final Report VOLUME 1 of 2. September 3, 2012. https://www.engroenergy.com/wp-content/uploads/2012/PDF/R2M03THP-Final_Report-ESIA_of_Thar_Coal_Block_II_Mining.pdf

Hagler Bailly 2013. Block VI Lignite Mining Project. http://www.oraclepower.co.uk/wp-content/uploads/2016/02/ESIA-of-Block-VI-Lignite-Mining-Project-Volume-1-of-3-R3E03TCO.pdf

Hagier Bailly, 2014. Thar Coal Block II Power Project Environmental and Social Impact Assessment Final Report Volume 1 of 2. https://www.engroenergy.com/wp-content/uploads/2012/08/Environmental-Social-Impact-Assessment-of-Thar-Coal-Block-II-Power-Project-Volume-I.pdf

Hubco, 2020. Growth Aspirations https://www.hubpower.com/growth-aspirations/

IEA, International Energy Agency, 2012. Water for Energy: Is Energy Becoming a Thirstier Resource? Excerpt from the World Energy Outlook 2012. Paris, France, OECD/IEA.

Imdadullah Siddiqui, 2007. *Environmental Study of Coal Deposits of Sindh, with Special Reference to Heavy and Trace Metal Study in Thar*, *Sonda and Meting-Jhimpir Coal Field*. Doctoral Thesis. National Center of Excellence in Geology. University Of Peshawar

Jamshed Ali, Tasneem G. Kazi, Jameel A. Baig, Hassan I. Afridi, Mariam S. Arain, Kapil D. Brahman, Naeemullah, Abdul H. Panhwar, 2015. Arsenic in coal of the Thar coalfield, Pakistan, and its behavior during combustion. *Environ sci Pollut Res* (2015) 22:8559-8566

Jaroskaw Badera, Leszek Pazderski, 2019. Effects of lignite surface mining on local communities: controversies and areas of negotiation. *Environ. Socio.-econ. Stud.*, 2017, 5, 3: 31-39

Javed Mirza, 2019. Sino Sindh Resources seeks upward revision in coal mining tariffs. Published in The News International September 13, 2019. https://www.thenews.com.pk/print/525549-sino-sindh-resources-seeks-upward-revision-in-coal-mining-tariffs

John Cornford, 2020. Mixed omens for Oracle Power. Published in Master Investor 08 April 2020https://masterinvestor.co.uk/equities/mixed-omens-for-oracle-power/

JICA -Japan International Cooperation Agency. 2013. Data Collection Survey on Thar Coal Field in Pakistan Final Report February 2013. https://openjicareport.jica.go.jp/pdf/12113221_01.pdf; https://openjicareport.jica.go.jp/pdf/12113221_02.pdf

Kalpana Kochhar, Catherine Pattillo, Yan Sun, et al and an IMF Staff Team, 2015. *Is the Glass Half Empty or Half Full? Issues in Managing Water Challenges and Policy Instrument*s. International Monetary Fund Strategy, Policy, and Review Department, https://www.imf.org/external/pubs/ft/sdn/2015/sdn1511.pdf

Khuhawar et al., 2019. Assessment of Water Quality of Groundwater of Thar Desert, Sindh, Pakistan
J Hydrogeol Hydrol Eng 2019, 7:2.

Mac Kirby, Mobin-ud-Din Ahmad, 2016. *Time series (1980-2012) crop areas and production in the districts and canal commands of Pakistan*. A report prepared under the Sustainable Development Investment Portfolio of the Department of Foreign Affairs and Trade. CSIRO Land and Water, Australia. publications.csiro.au/rpr/download?pid=csiro:EP163815&dsid=DS5

Mahessar, Ali & Mukwana, Kishan & Qureshi, Abdullatif & Ehsan, Muhammad & Leghari, Haq & Manganhar, Abdul., 2016. Assessment of Water Quality of LBOD System and Environmental Concerns. *Journal of Engineering, Science & Technology*. 15. 32-39

Mahessar AA, Qureshi AL, Ursani H , Tunio I, Kandhro Band Memon SA. 2017. Environmental Concerns for Water Consumption from Polluted Water Bodies in Watershed Area of Sindh Province*. J Pollut Eff Cont* 2017, 5:4 DOI: 10.4176/2375-4397.1000204

Maulbetsch J, DiFilippo M, 2003. Spray cooling enhancement of air-cooled condensers. Report 1005360, Palo Alto, CA, USA, Electric Power Research Institute, 142 pp (Sep 2003)

Mott MacDonald, 2015*. Strategic Environmental and Social Assessment (SESA) Environmental and Social Studies, Land Use Plan including Resettlement Frameworks for Thar Coal Fields* June, 2015.

Nabi, G., Ali, M., Khan, S. *et al.* The crisis of water shortage and pollution in Pakistan: risk to public health, biodiversity, and ecosystem. *Environ Sci Pollut Res* **26,** 10443–10445 (2019). https://doi.org/10.1007/s11356-019-04483-w:

Nadeem Arif, 2019. *Recycling of Water from Thar Coal Mines*. In Water Stress. Proceedings of the 13th Symposium of The Pakistan Academy of Engineering. http://www.pacadengg.org/pdf/Programmes/13th%20Symposium%20Proceedings%20for%20Publication%20final.pdf

Naeem A. Mughal, Yasmin Nergis, 2018. Environmental Impact Assessment of Potential Mining Concerns at Thar Coal Fields and Their Remedies*. J. Engg. and Appl. Sci*. Vol.37 No,1 January-June 2018. DOI: https://doi.org/10.25211/jeas.v37i1.2319

Natural Disaster Consortium, 2019. Sindh Drought Needs Assessment (SDNA) Report. https://reliefweb.int/report/pakistan/sindh-drought-needs-assessment-sdna-report-january-2019#:~:text=The%20detailed%20assessment%20was%20conducted,to%20provide%20recommendations%20to%20the

Nayyer Alam Zaighaml, Mujeeb Ahmadl, and Noushaba Hisam, 2012. *Thar Rift and its Significance for Hydrocarbons*. Search and Discovery Article #20146 (2012)

Oracle Coalfields PLC, 2017.*Thar Coalfields Block VI 2x330MW Coal-Fired Power Plant.* Environmental and Social Impact Assessment. 4 volumes. March 2017.

Oracle Coalfields, 2011. Bible of Transaction Documents. AIM Admission to the London Stock Exchange. http://www.oraclepower.co.uk/wp-content/uploads/2016/02/Oracle-Coalfields-plc-AIM-Admission-Document.pdf

Pakistan Food Security Cluster (FSC), 2017. Livelihood and Food Security Assessment (LFSA) Jamshoro, Sanghar, Umerkot and Tharparkar (Sindh-Pakistan) - November 2017. https://reliefweb.int/report/pakistan/livelihood-and-food-security-assessment-lfsa-jamshoro-sanghar-umerkot-and-tharparkar

Private Power and Infrastructure Board, 2008. Pakistan's Thar Coal Power Generation Potential. http://embassyofpakistanusa.org/wp-content/uploads/2017/05/Thar-Coal-Power-Generation.pdf

PPI, 2019. Murad Ali Shah urges Irrigation Department to complete water supply scheme for Thar Coalfield. Published in PPI April 24, 2019. https://ppinewsagency.com/murad-ali-shah-urges-irrigation-department-to-complete-water-supply-scheme-for-thar-coalfield/

Qureshi, Abdullatif., 2015. Impact of Releasing Wastewater of Sugar Industries into Drainage System of LBOD, Sindh, Pakistan. ", International Journal of Environmental Science and Development (IJESD). 6. 381-386. 10.7763/IJESD.2015.V6.622.

RWE International, 2009. Thar Bankable Feasibility Study. https://www.rwe.com/web/cms/mediablob/en/315572/data/227000/1/rwe-technology-international/mining-services/Thar-Bankable-Feasibility-Study.pdf

SECMC & Engro, 2018.Effective Utilization of Water in Thar Coal Projects. file:///D:/WKA/Countries/Pakistan/Mine%20effluent/EFFECTIVE%20UTILIZATION%20OF%20WATER%20IN%20THAR%20COAL%20PROJECTS.pdf

Sindh Carbon Energy Limited, 2013. Environmental and Social Impact Assessment Block VI Lignite Mining Project. http://www.oraclepower.co.uk/corporate-social-responsibility/esia/

Sindh Carbon Energy Limited, 2013. *Environmental and Social Impact Assessment Block VI Lignite Mining Project* – 3 volumes.

Sindh Engro Coal Mining Company, 2014.Thar Coal Block II Power Project Environmental and Social Impact Assessment .Final Report. 2 volumes. January 21, 2014.

Singh, R. N., Atkins, A.S., and Pathan, A.G., 2010. Determination of ground water quality associated with lignite mining in arid climate. *International Journal of Mining & Environmental Issues*, vol. 1, No.1.

Singh, R. N., Anthony S., and Abdul G., 2010. Water Resources Assessment Associated With Lignite Operations in Thar, Sindh, Pakistan. Arch. Min. sci., Vol. 55 (2010), No 3, p. 425-440

Singh, R. N. Atkins, A. S. and F. Doulati Ardejan, 2012. Hydrogeological Issues Concerning the Thar Lignite Prospect. *Int. J. Min. & Geo-Eng.* (IJMGE), vol. 46, No. 2, Dec. 2012, PP. 141-156

Sino-Sindh Resources, 2012. *Environmental & Social Impact Assessment (ESIA) Study Of Thar Coal Mining In Block* - 1 Final Report May 2012.

Shahbaz Rana, 2016. Five CPEC projects face the axe *Published in The Express Tribune, July 20th, 2016. https://tribune.com.pk/story/1145535/five-cpec-projects-face-axe/*

Shujauddin Qureshi and Zeenia Shaukat, 2019.*Thar Coal Project and Local Community Documenting Views and Experiences of Stakeholders*. National Commission for Human Rights (NCHR) Report.

Shukla V, 2018. Pakistan's alarming water crisis: country to run out of clean water by 2025. Politics. https://www.valuewalk.com/2018/05/pakistan-water-crisis-clean-water-2025/.

Soomro, Z. A., M. Ashraf, K. Ejaz, A. Z. Bhatti, (2018). Water Requirements of Major Crops in the Central Punjab. Pakistan Council of Research in Water Resources (PCRWR), pp. 44. file:///D:/WKA/Countries/Pakistan/irrigation/Major%20Crops%20Central%20Punjab.pdf

South Asia Citizens Web, 2008. LBOD project in Southern Pakistan is a social and ecological disaster - 'People's Tribunals' of 2008 and 2007. http://www.sacw.net/article264.html

Syed Abul Fazal Rizvi, 2018. Effective Utilization of Water in Thar Coal Projects. Sept 19, 2018. file:///D:/WKA/Countries/Pakistan/Mine%20effluent/EFFECTIVE%20UTILIZATION%20OF%20WATER%20IN%20THAR%20COAL%20PROJECTS.pdf

The third pole, 2020. In Pakistan the Thar desert waits for a canal. https://www.thethirdpole.net/2020/06/17/in-pakistan-the-thar-desert-waits-for-a-canal/

The News International, October 3, 2006, Centre to build Makhi-Farash link canal. https://www.thenews.com.pk/archive/print/645899-centre-to-build-makhi-farash-link-canal

The News International, 2018. *Extraction for Thar coal not to impact drinking water*. Published March 10, 2018. https://www.thenews.com.pk/print/290540-extraction-for-thar-coal-not-to-impact-drinking-water

The Louis Berger Group Inc., 2012. Sindh Irrigation and Drainage Authority Sindh Water Sector Improvement Project Phase-I (Wsip-I) Preparation of Regional Plan for The Left Bank of Indus, Delta And Coastal ZONE Phase – III Draft Report Regional Master Plan for the Left Bank of Indus, Delta and Coastal Zone. http://sida.org.pk/download/lbg/phaseIII/Volume%20I%20&%20II%20-%20Draft.pdf

Thar Voice Forum, 2016. *Thar Coal and Indigenous People Gorrano Effluent Pond Issue and its Solution.* Thar Coal Context December 25, 2016.

USGS – United States Geological Survey, 2008. Minerals Yearbook, 2008, V. 3, Area Reports, International, Asia and the Pacific. https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/country/2008/myb3-2008-pk.pdf

Wandrey, C.J. and Law, B.E, 1998, Maps showing geology, oil and gas fields and geologic provinces of South Asia: U.S. Geological Survey Open-File Report 97-470-C, 10 p., https://doi.org/10.3133/ofr97470C.

World Bank. 1998. *Pakistan - Left Bank Outfall Drain Stage-1 Project (English)*. Washington, DC: World Bank. http://documents.worldbank.org/curated/en/835791468077930041/Pakistan-Left-Bank-Outfall-Drain-Stage-1-Project

Yasmin Nergis , Muhammad Jahangir KhanI,Naeem A. MughalI, Mughal Shareef, Jawad Abdullah Butt. 2018. Management of Ground Water Hazard: A Case Study from Thar Coal Mines, Pakistan. *Int. J. Econ. Environ. Geol*. vol. 9 (4)68-73, 2018.

Zardari, H.H., Shirazi, S.M. N. Farahen, N., & Irena, N.,2016. Operational efficiency and up-coning problem of scavenger wells in lower Indus Basin of Pakistan, Desalination and Water Treatment, 57:60, 29178-29191, DOI: 10.1080/19443994.2016.1196558

Zaigham, N.A., 2002. Strategic sustainable development of groundwater in Thar Desert of Pakistan. *Science Vision*, 7(3-4), 61-74.