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Improved governance of perennial water for mitigating climate risks in arid and semi-arid regions - An example from spate area of Pakistan

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Abstract

The study reviews existing irrigation system management in the command area of Tank Zam in Khyber Pakhtunkhwa and explores effective ways of using scarce perennial water for a better response to climate change related stress. The area falls in arid zone with an annual average rainfall below 250mm. The Spate irrigation, an ancient system of water management is used in the area. Availability of a perennial water source serves a huge security for the farmers. The study uses primary and secondary data. Climate data has been used for analysis of water availability in the wake of climate change. The study shows that during winter season the irrigation water supply is irrigating 1735 hectares but during summer even this area could not be irrigated. The irrigation application efficiency is very low. The decadal changes in precipitation show an increasing trend up to 2030 and then indicating gradual decreasing trends till 2040. Winter and fall rains are continuously decreasing till 2040. Spring Rain are increasing till 2040. Summer rains are increasing up to 2030 and then gradually decreasing till 2040. Temperatures in all the seasons are increasing. Eventually perennial flow will also receive great stress resulting in less availability of irrigation water. Seeing this trend together with irrigation inefficiency in the field, the issue of better governance of the perennial water supply becomes very important. The study recommends a critical review of existing water management system for improved water governance through structural changes and revitalizing social aspects to support effective governance.

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Introduction

Pakistan's diverse natural resource base provides a variety of valuable products and services to support livelihoods of the rural poor. Out of the total area of 88.2 million hectares in Pakistan, 29.42 million hectares (36.59%) of geographical area is culturable and 21.17 million hectares is cultivated area which is 72.27% of culturable land (GoP, 2018a). The irrigated area is 17.82 million hectares (60.67%) of the culturable land (GoP 2018b). The same percentage in case of Khyber Pakhtunkhwa province of Pakistan, where the study was conducted, is 34% (Khan, 2019). Growth rate of agriculture sector is 3.81% (July-Feb 2018) which, besides others, is mainly linked with the rainfall timing and other climatic conditions. This in general may be counted as a discouraging situation for a country having an agro-based economy and lot of efforts and planning is required to improve the agriculture sector. Approximately 75% of the country falls in arid and semi-arid zone with an annual average rainfall below 250mm. The Spate irrigated areas form a substantial proportion of drylands in Pakistan with roughly an area of 1.4 million hectares which is 9% of the total irrigated area (Khan *et al.*, 2014). Spate irrigation is an ancient system of water management unique to semi-arid and arid environments, found in the Middle East, North Africa, West Asia, East Africa and parts of Latin America.

In Spate irrigation system, fields are irrigated through storing water from seasonal floods of rivers, streams, ponds and lakes. The essential element of Spate is flooding the ground either using natural flood from rains in an upstream macro-catchment or creating a flow to irrigate a larger ground. It is a huge management effort to optimize flow of water. A defining characteristic of Spate is unpredictability and labour intensity since the number and quantity of floods on which the availability of irrigation water depends vary from one year to another. Water is diverted from normally dry streambeds when the stream is flooded. The flood water is then diverted to the fields. This may be done by free intakes, by diversion spurs or by bunds built across the riverbed. The most accurate estimate of the area under spate irrigation brings it close to around 2.6 million hectares, but the nature of spate irrigation is such that the acreage varies from year to year depending on rainfall (Mehari, *et al.*, 2010). The largest area under spate irrigation is situated in Pakistan (1,402,000 hectares) on which 3.0 million families depend (Nizami and Khattak 2014; Khan *et al.*, 2014). Despite the size and its importance in poverty alleviation, the Spate area is nearly invisible in programmes and policies of government and civil society. It covers the entire or major portions of the cultivable land in the districts of Tank, DI Khan, Lakki Marwat, Bannu, Karak, Kohat (KP), DG Khan, Rajanpur, Mianwali (Punjab), Kacchi, Sibi, Jhal Magsi, Qila Saifullah, Loralai, Musakhel, Barkhan, Lasbela (Balochistan) and Dadu, Larkana, Jamshoro, and Thatta (Sindh) in Pakistan. This kind of Spate system is termed differently in different areas. It is called Rudh Kohi in KP and Punjab, Sailaba in Balochistan, and Nai in Sindh (ibid).

While Spate floods are crucial for livelihoods of dwellers in semi-arid and arid areas, it is a highly unpredictable in its nature and a victim of climate variability (too much, too little or no water). Floods often do not arrive at an expected time when farmers need water most. Therefore, farmers' livelihoods and all the agricultural investment (including seed, fertilizer) remain at the mercy of water and are risked to being lost. In this context, presence of a perennial water source is a huge security for the farmers in a semi-arid and arid region such as Tank. This is the only resource, although limited in quantity that mitigates risks farmers face in the drylands of Spate areas.

The current changing climate scenario presents a high risk to the achievement of water and food security. This is especially true for developing areas, owing to limited adaptive capacities, are more vulnerable to the risks posed by climate change (Asad, S. A., 2016; Zulfiqar, 2018). The looming climate change impact puts further pressure on available water resources. Therefore, finite water resources need to be managed in a way that competing water requirements including domestic, food production, industrial development, protecting ecosystems, etc. are met adequately and efficiently.

The Sustainable Development Agenda 2030 formally adopted by the United Nations member states defines the Goals within which to work to improve agriculture, water governance and food security (Hayat, N, 2016). Pakistan's National Climate Change Policy (GoP, 2012) and National Water Policy (GoP, 2018) are steps towards addressing water and food insecurity in the wake of climate change. This study analyses the significance of perennial water in arid context of Tank Zam. The Zam is local terminology used in southern KP for a watershed where hill torrents are received and are then channelized by farmers for irrigation. The study reviews existing operational framework of irrigation system management and explores most effective governance of perennial water for a better response to climate change related stress.

Materials and methods

The study area

The study area chosen for this research is Tank Zam and command area under its perennial water. Tank Zam is located in district Tank of Khyber Pakhtunkhwa Pakistan. It lies between 32°27' North latitude, and 70°38' East longitude. The total area of tank is 1679 square kilometers (km^2). The climate in Tank is cold and harsh in winters in the mountains to the west. Tank is predominantly rural, with 87 percent from a total population of 394,885 people living in rural areas (GoP, 2017). The summer is extremely hot and scorching. People make their livelihood by farming and business. Farming in Tank depends on irrigation resources. A large part of Tank is fed by Rudh Kohi Spate system of irrigation depending on floods.

Despite that Tank is an agrarian district; farming is practiced mostly at subsistence level. The economy of the district is water dependent which means water is lifeline of the inhabitants of the district. The district is endowed with a total land area of 166,000 hectares out of which cultivable area is 113,000 hectares (GoKP, 2017) depending on access to water for irrigation. Due to water constraints, only about 28,443 hectares were reportedly cultivated in 2017 (Helvetas, 2017) leaving 84,557 hectares as culturable waste. The total irrigated area with regular and reliable source is 14,628 hectare that constitutes about 13% of the total cultivable and about 51.4% of cultivated area. The major source of irrigation in this case is tube wells (82%) and perennial water flow (GoKP, 2017).

Tank Zam is located in the Frontier Region of Tank district at an altitude of 422 meters from the sea level. Tank Zam has a catchment area of 2357 km^2 with a total water right area of 41014 hectares (www.nceg, 2010). Both Tank and neighboring DI Khan together have 27% of their total land mass under Rudh Kohi system in Pakistan (GoKP, 2019). There are 30 Rudhs[1] in Tank and DI Khan, a few shared, that carry both perennial flows and flood water in the Zams. Tank Zam water flow is distributed into six Rudhs called Rudh Kiryani, Rudh Lowra, Rudh Pir Kuch, Rudh Chowa, Rudh Sidqi and Rudh Takwara. The Zam has perennial water stream with command area of 1735 hectares in the upstream reaches (Khan, 2019). The total length of conveyance system is about 307 km and number of diversion structures (locally called *Gandies/sads*) for irrigation is about 81 (ibid).

According to GoKP, 2017, area cultivated in winter (*Rabi*) in Tank was 15,566 hectares. Wheat is the most dominant *Rabi* crop in the farming system of Tank occupying 83.34% area followed by Gram on 10.04% area. Winter vegetables and fruits occupy 2.24% and 0.1% area respectively whereas Lentils (pulses) cover 2.27% area. Rape, mustard and barley crops each occupy around 1% area. Area cultivated in summer (*kharif*) is 1982 hectares. Sugarcane is a dominant crop during *kharif* occupying 33.60% followed by vegetables with 29.72% and fruits 13.67% area. Other important crops include rice (8.12%), maize (5.40%), Jowar (4.39%), guar (3.53) and millet (1.56%) in *kharif* (GoKP, 2017). A comparison of yields from important crops is detailed in Table-1 indicating that most yields in Tank are considerably below the provincial averages.

[1] Rudhs are streambeds which receive seasonal and perennial waters in Zam.

The data shows that Tank is doing better only in case of Gram i.e. 106% of the average yield in the province.

Table 1. Comparison of Important Crops' Yields: KP vs Tank District (2016-17) Kg/ha.

Wheat		Maize		Gram		Rice		Sugarcane	
KP	Tank	KP	Tank	KP	Tank	KP	Tank	KP	Tank
1823	1408	1880	1411	507	535	2362	1360	47471	19956
% of Province:	77%		75%		106%		58%		42%

Source: Crops Statistics Khyber Pakhtunkhwa 2016-17, Agriculture Department Govt. of KP.

Methodology

A comprehensive questionnaire was developed for collecting data through Focus Group Discussions (FGDs) and Key Informants Interview (KIIs) pertaining to water and agriculture practices etc. Twenty-four (24) farmers, four from each channel (Rudh), were interviewed in Tank Zam. The Tank Zam was visited at the location where perennial water is distributed into six main Rudhs (channels / streams). The water flow measurement data were collected twice during the field visit. The measurement was taken using flow measurement equipment. Water flow was measured in all the six Rudhs i.e. Takwarra, Sidki, Shahrawan, Pir Kuch, Lorra and Crany. Transact walks were conducted in the villages to observe water channels and standing crops in the focused area.

The water flow of perennial stream of Tank Zam was measured to assess the total flow of the stream during wheat cultivation. Measurements were taken in the presence of revenue staff responsible for revenue collection and allocation of water for irrigation.

Secondary data on climate scenario (Helvetas, 2019) have been obtained for further analysis on water availability in view of climate change.

Results and discussions

Perennial Water Flow

The Tank Zam command areas possess three types of water sources i.e. Perennial water that emerges from the springs with some snow melts and flows through the Zam, Hill torrents flood (Rudh-kohi) also flowing through Zam and underground water extracted through tube well or other means to irrigate area under the command of Tank Zam. Water in Tank Zam flows into six Rudhs (GoKP 1995). Except Rudh Takwara, which also irrigates some area lying in Dera Ismail Khan (DI Khan) district, the other Rudhs irrigate the area exclusively in district Tank. Besides, Shuze Nulla and Suhali Nulla also joins Takwara downstream near Gul Amam and flow downstream towards east till it join River Indus.

The water flow of perennial stream of Tank Zam was measured by the team to assess the total flow of the stream. During the measurement, a senior revenue officer (known as *Tehsildar*) with his staff was present on the site and diverted the major portion of the flow (94.15cfs[2]) towards the Sharawan canal, supplying drinking water to the city, by closing some of the other outlets, followed by Lora with discharge of 10.46 cubic feet per second (cfs) and Karyani had a flow discharge of 4.61cfs with a total Tank Zam perennial flow discharge of 109.22 cfs. A second measurement was made on the subsequent days during the year to re-confirm the quantity of perennial water flowing in the Tank Zam. On the 2nd day, the water was distributed amongst various Rudhs and total flow was measured as 108.41 cfs. It was observed that the Tank Zam perennial flow was divided into seven branches. The flow discharge recorded in each branch is given in Table 2.

Table 2. Flow discharge measured in streams of different Rudhs of Tank Zam.

S. No.	Name of the Rudh/ Streams	Flow Discharge (cfs) measured	
		Measurement 1, 2016	Measurement 2, 2016
1	Karyani	4.61	14.63
2	Lowra	10.46	10.79
3	Sharawan	94.15	36.91
4	Sidqi	0.00	20.85
5	Takwara	0.00	7.93
6	Bahader Khel	0.00	15.72
7	Ibrahim	0.00	1.58
	Total Flow	109.22	108.41

Source: Field Survey/measurement

It may be seen from Table-2 that the amount of water flowing in Sharawan was relatively large (36.91cfs),

[2] Cubic feet per second

followed by Sidqi (20.85cfs) and Bahader Khel of 15.72cfs. The average flow of Tank Zam recorded was 109.22 and 108.41cfs at different measurements despite the variation in the individual streams. In general, the variations in flow discharge of perennial stream of Tank Zam is relatively small throughout the year, except during the flood season (July-August) when the flow discharge became significantly larger as reported by the Key Informants.

During daytime, the Revenue staff on duty diverts major flow towards Sharawan branch of the canal to ensure domestic water supply to Tank city. At night, the flow is divided by the farmers into different branches to irrigate their fields. However, the water rights are not strictly adhered to in the upper reaches. These water rights are documented in the water rights book of revenue called *Kulyat o Riwajat e Abpashi*. These are regularly updated by a special revenue officer assigned to manage spate watershed. The irrigation from perennial stream of Tank Zam is practiced by water right-holders and also those farmers who do not possess water right in the upper most reaches of the Zam. This sometimes also results in conflicts as reported by the key informants. Out of the six Rudhs, only three Rudhs i.e. Sadqi, Lowra and Chowa get regular perennial water. Of total perennial water, Rudh Sadqi receives 3/5 water (60%), whereas Rudh Chowa and Rudh Lowra receive 1/5 (20% each) water. The officially recognized water distribution rights from Tank Zam is reflected in Table 3.

Table 3. Perennial stream water distribution of Tank Zam.

S. No	Description	Share in *Jandra*[3]	Share in cfs
1	Nawab of Tank	1.00	4.00
2	Shekhan and Pirans	0.50	2.00
3	Government buildings	0.50	2.00
4	Domestic water use	0.25	1.00
	Remaining	9.75	39.00
6	Rudh Sidqi	4.50	18.00
7	Rudh Chowa	3.75	15.00
8	Rod Lowra	1.50	6.00

Source: From the old record of the Revenue Department, district Tank collected in 2017.

[3] One *Jandra*, a water flow measuring unit in local language, is equal to 4.0 cfs.

Perennial use of water and Irrigation Practices

The perennial water of about 65cfs is used for irrigation. In 2017, about 2,470 acres was being irrigated through Tank Zam. The average landholding is 6.68 acres. The irrigation water flow, time and depth of application per irrigation assessed through the data collected from farmers is given in Table-4.

The analysis of Table-4 shows a wide range of water depth applied; 0.40 to 1.59 feet depth of water applied per irrigation due to large field size with uneven topography for the same crops in the same season. Normally, in the irrigated regions of Pakistan 0.25 to 0.30 ft of water depth is applied per irrigation. Thus, in Tank Zam perennial stream command area, there is a prevalent practice of excessively uneven and over irrigation, resulting in very low water use efficiency. The field sizes are relatively large and usually not precisely levelled, therefore the farmers are applying more depth of water per irrigation than it is required as shown in Fig. 1.

Table 4. Land holding, flow discharge, time and depth of water application

S. No.	Farmers	Village	UC	Flow Q (cfs)	Area (acres)	Time (hrs)	Water Depth (ft)
1	Farmer-1	Umar Ada	Warspoon	8.00	15.00	24.00	1.06
2	Farmer-2	Baba Khail	TaTa	4.00	5.00	24.00	1.59
3	Farmer-3	Tatoor	Jata Tar	8.00	25.00	24.00	0.63
4	Farmer-4	Lati	TaTa	4.00	6.25	24.00	1.27
5	Farmer-5	Lati	TaTa	4.00	9.13	24.00	0.87
6	Farmer-6	Kirrihaider	Warspoon	4.00	9.13	24.00	0.87
7	Farmer-7	Kirrihaider	Warspoon	6.00	10.00	24.00	1.19
8	Farmer-8	Kirrihaider	Warspoon	16.00	8.75	10.00	1.51
9	Farmer-9	Kirrihaider	Warspoon	12.00	10.00	5.50	0.55
10	Farmer-10	Kirrihaider	Warspoon	4.00	6.25	10.00	0.53
11	Farmer-11	Sekhei	--	4.14	5.81	7.59	0.38
12	Farmer-12	Kirrihaider	---	6.00	10.00	10.00	0.50
Average				6.68 ±3.84	10.03 ±5.42	17.59 ±8.02	0.91 ±0.41

Source: Field Survey.

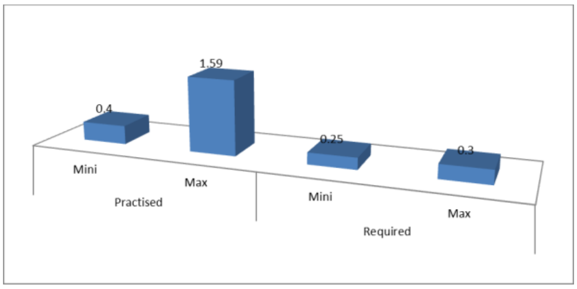

Fig. 1. Farmers' Practice vs Required Irrigations Appllication in ft.

The irrigation practices observed, and discussions held with the farmer suggest that the farmers are not using appropriate irrigation practices resulting in low water use efficiency. They are applying more water than is required. Also, there are several water losses in the system due to poor conveyance and structure failures.

Farming system and water demand

The Tank Zam has a total perennial stream of 108.41cfs. The water is used for domestic water supply and irrigation in the upstream reaches towards west of Tank City. The water is supplied through unlined channel and results in significant losses in the conveyance system. In view of prevailing situation, an analysis has been made about how much more area could be brought under cultivation within the available water supply assuming that recommended efficient water management practices are adopted and further that about 60cfs be made available for irrigation and 40cfs to meet the domestic water need of Tank City. An analysis of irrigation water supply and demand during winter season and summer session is shown in Fig. 2.

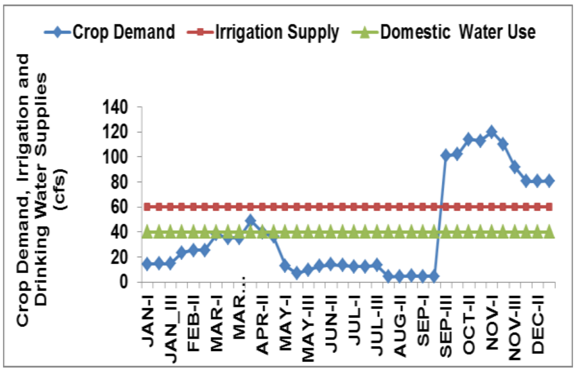

Fig. 2. Crop Water Demand and Supply in the Perennial Stream Command Area of Tank Zam.

As already described in Table 2, assuming that water supply will remain more or less constant throughout the year, the water demand analysis reveals that during autumn / winter seasons, the irrigation water demand will rise in the command area. During spring and summer, the irrigation water may be enough to fulfill irrigation and domestic demands (with some exceptions during March and April when irrigation and domestic demands may compete with each other). During summer, the situation remains under control also due to some rainfall received in the catchment. Therefore, a significant cultivated land is left fallow. In general, the irrigation water demand ranges from 4.61 to 120cfs with overall average of 32.63cfs. Given that 50% water losses may be saved with proper management/governance and lining of irrigation channel to pull down the irrigation demand curve below the supply line, the demand for water is still very high during fall and winter. This is due mainly to wheat and sugarcane cultivation when a wide gap between demand and supply is created. This analysis brings us to two conclusions:

1. Whatever may be the adaptation and water governance strategy in the dry and drought prone context of Tank, it needs to focus on these months when the stress is the highest
2. There is a need to critically analyze cropping pattern during this season. Sugarcane is a high delta crop. Coupled with over irrigation and inadequate water efficiency management, sugarcane consumes the largest share of meagre water which can be saved to bring a huge area left fallow due to no water.

These arguments need to be supplemented with cost and benefits analysis of the entire farming system in Tank by giving a monetary value to water and water management. It is important to assess in monetary terms what farmers and state are receiving out of putting precious resources into sugarcane as oppose to other possible alternatives such as gram and lentils which demonstrate above average results in terms of yield in Tank.

The Climate change argument in Tank

The findings and debate noted above on demand and supply of water and judicious use of perennial water need to be analyzed from the lens of climate change scenario in Tank. The decadal changes in precipitation for Tank against base years (1981-2010) are shown in Table 5 and the Fig. 3.

Table 5. Annual and seasonal rainfall projections for Tank (1981-2040).

Rainfall (mm)	Base	Projected	% change From Base	Projected	% change From Base	Projected	% change From Base
	1981-2010	2011-2020		2021-2030		2031-2040	
Annual	390.5	413.2	5.81	421.4	7.91	416.1	6.56
Winter	81.2	70.3	-13.42	60.7	-25.25	54.4	-33.00
Spring	122.6	142.2	15.99	151.5	23.57	158.7	29.45
Summer	175.5	191.6	9.17	201	2.00	196.6	12.02
Fall	11.0	9.0	-18.18	8.2	-25.45	6.4	-41.82

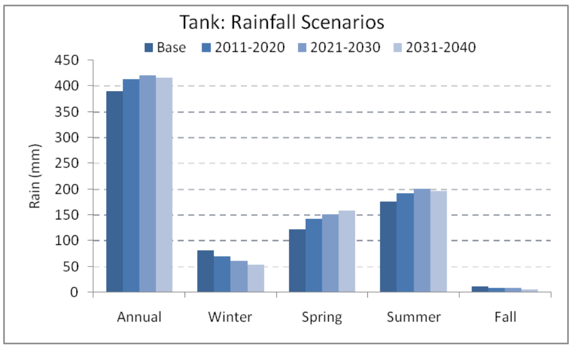

Fig. 3. Tank District Rainfall Scenarios.

Decadal temperature scenarios for Tank are shown in Table 6. These are analyzed by seasons and graphically represented for minimum and maximum projected temperatures in Fig. 4 & 5.

Table 6. Annual and Seasonal Temperature Projections for Tank (1981-2040).

Temperature (°C)	Base	Projected	% change from Base	Projected	% change from Base	Projected	% change from Base
	1981-2010	2011-2020		2021-2030		2031-2040	
Annual							
Average	26.0	26.8	3.1	27.2	4.6	27.4	5.4
Minimum	19.1	20.0	4.7	20.3	6.3	20.4	6.8
Maximum	32.9	33.5	1.8	34.0	3.3	34.3	4.3
Winter							
Average	16.5	17.1	3.6	17.6	6.7	17.7	7.3
Minimum	9.1	9.7	6.6	10.1	11.0	10.1	11.0
Maximum	23.9	24.7	3.3	25.4	6.3	25.6	7.1
Spring							
Average	24.5	25.1	2.4	25.5	4.1	25.9	5.7
Minimum	17.5	18.0	2.9	18.3	4.6	18.6	6.3
Maximum	31.6	32.3	2.2	32.8	3.8	33.3	5.4
Summer							
Average	33.9	34.5	1.8	34.9	2.9	35.1	3.5
Minimum	27.5	28.0	1.8	28.3	2.9	28.4	3.3
Maximum	40.4	41.1	1.7	41.6	3.0	41.9	3.7
Fall							
Average	29.0	29.9	3.1	30.6	5.5	30.9	6.6
Minimum	22.2	23.2	4.5	24.0	8.1	24.4	9.9
Maximum	35.8	36.6	2.2	37.2	3.9	37.4	4.5

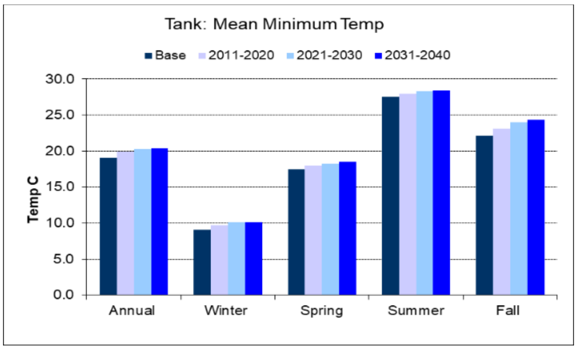

Fig. 4. Tank District Mean Minimum Temperature Scenarios.

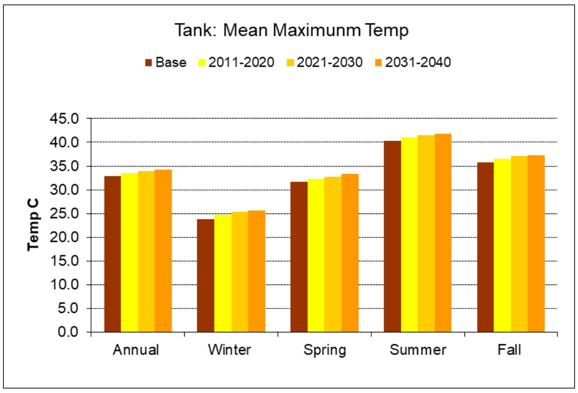

Fig. 5. Tank District Mean Maximum Temperature Scenarios.

The climate data and scenario 2040 suggest the following:

Rainfall

Annual Rain show an increasing trend up to 2030 and then indicating gradual decreasing trends till 2040. Winter and fall rains are continuously decreasing till 2040. Spring Rain are increasing till 2040. Summer rains are increasing up to 2030 and then gradually decreasing till 2040.

Temperatures

All the temperatures in all the seasons are increasing. Most striking feature is an increasing minimum temperature in fall seasons (warmer night). As oppose to this, maximum temperature is not increasing at the same rate implying that the day and night temperature difference may increase. All other temperatures are increasing at the same rate.

This analysis confirms increasing water stress in Tank. One, rain in general is heavily decreasing during fall and winter when wheat sowing is due. In addition, fall nights are warmer which is not a favorable situation for wheat germination in a heat surplus zone. Lack of rainfall is a climate event not just limited to Tank; climate in the source region of perennial water also demonstrates similar trends, suggesting, that eventually perennial flow may start receiving great stress resulting in less availability of irrigation water. The effect of temperature can only be managed through irrigation / rainfall regime – which seems to be in under stress. Another important element in this regard is declining summer rainfall. Seeing this trend together with irrigation inefficiency in the field, the question is whether sugarcane is the right crop for water stressed arid / semi-arid Tank. Certainly not in the long run. The wise use of perennial water will be the key to sustain livelihoods in water stressed Tank, especially during an extended Rabi season when no flood water is available (early fall to late spring).

Conclusion

Taking the example of Tank Zam, the study leads to further probing and identifying several measures for a more effective governance of precious perennial water in an arid/semi-arid area. A rigorous move for better water productivity in agriculture is the only way to offset water and climate stress in the region. While it is important to also improve water infrastructure and regulate canals from the source to the end of the fields, it is also important to address other non-structural aspects for improved water governance such as:

- Social mobilization and capacity building of the communities and relevant development departments to make them aware of the economic potential of water flowing through Tank Zam, formation of water users associations and their training in water management and crop husbandry, establishment of water turn system (*warabandi*) on equitable basis, management of watercourses, providing optimal depth of irrigation, land leveling and reducing fields size to appropriate sizes.
- A critical review of cropping system in Tank with respect to limited availability of water in the climate context of arid and semi-arid region. A switch to high value low water demanding crops (e.g. Gram, lentils) may be an important adaptive strategy.
- Supplement this with cost and benefits analysis of the entire farming system in Tank by comparing sugarcane, wheat, lentils and gram.
- Structural measures to save water losses such as lining of watercourses, regular land levelling, lining of channels, switching to high efficiency irrigation systems and reducing fields size to appropriate sizes for a proper control of water management.
- Although, Tank Zam perennial water flow provides livelihood to thousands of people, it possesses the potential of supporting many more in a sustainable manner if provided with a specific policy or institutional framework to develop it into a vibrant economic source. The present situation of Tank Zam deserves attention from the government and other stakeholders to tap its development potential and improving the socio-economic condition of the poor masses living in the area.

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