Research Article

Impact of Climate Change on the Confined Aquifers Resources and Factors Responsible for Decline and Vulnerability of Groundwater in District Karak

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Abstract | This study investigated the impact of climate change on the confined aquifer resources and discovers climate factors responsible for groundwater decline in district Karak, Khyber Pakhtunkhwa, Pakistan. The key objectives were comparing the community perception regarding groundwater recharge and discharge over the last decade and investigating the climate change impact on groundwater table. A total of 285 households with groundwater pumping facilities were selected for study within six villages; Kiridhand, Jangerizi Banda, Yaghi Musakan, Hassan Banda, Takht Nasrati and Garang. Data were collected through questionnaires, while secondary data was from different climate and weather reports. Binary Logistic model was used for analysis. The study discovered lack of surface water resources and ground water extraction satisfied the community needs and rainfall was only recharge method. Boreholes pumping technique was used mostly for irrigation. The Logit model investigated the impact of climate change was responsible for 73 percent variation in groundwater level. These climate factors included precipitation (Rainfall), temperature, humidity and delayed seasons. Rain patterns such as decrease in rainfalls with low frequencies showed positively significant impact on the groundwater level as climate factor and decline in rainfall showed significant positive effect. Groundwater was also highly significant and positively affected by the rising temperatures as the respective coefficient was 4.19 and p-value was 0.000. Delay in seasons showed significant and positive effect. The study recommended an approach of integrated water resource management to bring together relevant government departments, knowledge institutions, stakeholders and political leadership to an attractive option of climate change adaptation for groundwater resources preservation at district Karak.

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Introduction

Climate change means the change in the climate with time either because of human interference or any natural variations (Anon, 2007). Human activities change the composition of atmosphere i.e. greenhouse gas emissions (Oxfam, 2009). The best example in the present scenario is global warming due green house gases like nitrous dioxide (NO_2), carbon dioxide (CO_2) and methane (CH_4) which are caused by human activities. In the 21st century climate change is a major threat to the environment and a global challenge to human lives and social conditions (Horn and Freeland, 2009). According to the fourth assessment report, 2007, Intergovernmental panel on climate change (IPCC), the warming of climate system is unevenly evident from the increase in global temperatures, melting of glaciers and increase in sea temperatures (Anon, 2007). Worldwide, more than one-third of the water used comes from underground (Famiglietti, 2014). Groundwater is one of the most important sources of freshwater for drinking purposes, out of which 99 percent freshwater easily available around the globe. The increasing population depends on groundwater resources resulting in more extractions of groundwater which lowered water tables in some areas (Tripathi and Issac, 2016). Groundwater has a central role in food security, agricultural system and now 60% groundwater considered for irrigation/production of more than 70% of food grain irrigation around the world (Zaveri, 2016).

Climate change and groundwater nexus

The challenges to understanding the effect of climate change on groundwater are distinctive because groundwater resources and hydrological processes are directly or indirectly affected by climate change, in ways that have not been sufficiently discovered (Dettinger and Earman, 2007). Rainfall is the primary source of groundwater recharge in the hydrologic cycle (Shrestha and Sthapit, 2015). According to Jorgensen and Yasin al-Tikiriti (2003) historical climate change affects groundwater resources, in parts of the Middle East that once supported economic development and irrigation and during the Stone Age it was the main cause of falling cultures there. Globally climate change contributes to approximately 20% of projected rises in water shortage (Sophocleous, 2004). Changes in global climate are affecting many processes like changing surface-water levels, the hydrological cycle and groundwater recharge to aquifers along with some other related impacts on human activities and natural ecosystems.

Groundwater in Pakistan

In the northern and northeast areas of Pakistan rainfall is received in good amount which gives about 80% of the total rainfall per annum (Talchabhadel *et al*., 2018). Throughout the country variations in the land over a relatively small area results in large diversity in rainfall whereas variability in the levels of the shallow groundwater in seasons is mainly due to variability in rainfall throughout the year (Thapa *et al*., 2018). Through groundwater abstractions Pakistan fulfils more than 50% of its overall needs for irrigation (Qureshi *et al*., 2009). Groundwater abstraction rates have been increasing annually as they exceeded 55 km^3 to 60 km^3 over the last decade (FAO, 2012). In addition, Khan *et al*. (2008) show that in North-East Pakistan the upper and the lower region of Rachna Doab are been dried for long terms and will decline groundwater levels up to 10-20 meters. Groundwater has the following main challenges: (1) groundwater tables are negatively affected by environmental disturbance, (2) diminishing trend in groundwater recharge as growing trend in groundwater extraction, (3) lack of dam developments and limited storage capacity have decreased water recharge, and (4) the utilization of groundwater resources through installation of 16,700 large capacity (0.084–0.14 m^3 sec-1) tube-well development on large scale has been playing a key role in groundwater depletion since the 1960s (Watto and Mugera, 2016). The southern regions of Khyber Pakhtunkhwa are suffering from groundwater related problems about 75% of the massive population. Additionally, the climatic variations in weather also provide adverse impacts on recharge of the groundwater that leads to putting the resource at risk by shifting rainfall patterns and quantity day by day. Therefore, this study is a pleasant addition to addressing declining level of groundwater table issue due to the CC impact in the Southern part of the province that might help bringing solutions.

Objectives of the study

The main objective of the study was to investigate the climate change impact on the declining ground water table in the study area.

Materials and Methods

Study area

District Karak was selected because of its dry and arid climate, also considering its geographical characteristics. The estimated area of the district was measured to be 1,302 sq mi (3,372 km^2). The district is surrounded by District Kohat in the North, Lakki Marwat in the south and Bannu in the southwest. Various districts of the Punjab province lie in the east separated by the mountainous border. The provincial administration subdivided the district into three tehsils which are tehsil Karak, tehsil Banda Daud Shahand and tehsil Takht Nasrati (Pakistan Bureau of Statistics, 2022). Two-thirds of district is covered by dust and blazing sand. The climate is non-monsoon, dry and semi-arid with coldest winters and hottest summers. Summer season lies between mid-May and mid-September, whereas November brings winter and March over it. But it rains in both summer and winter (February and April) because of the eastern mountain geography that creates special behavioral monsoon dynamics. Winter rains have stronger patterns and intensities than summer seasons. Relative humidity increases from 46% in June to 76% in August. Rainfed Agriculture is practiced as the primary income source after industrial sector. Wheat, gram, mustard, oats and few other rainfed varieties are major crops. Mining and drilling sector is also well-established with raw petroleum, natural gas, salt, Sulfur, Gypsum in abundant (Javed *et al*., 2019). The geography of the area to be studied is given in Figure 1.

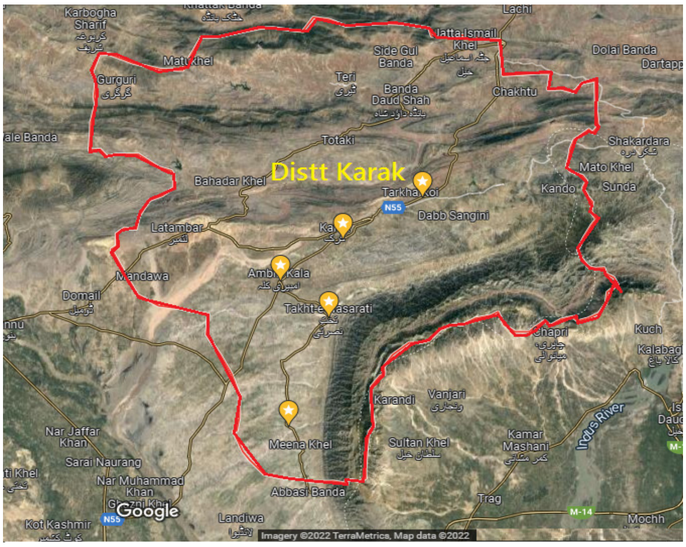

Figure 1: *Map of district Karak.*

Data collection

Tehsil Takht Nasrati was selected because of aquifers and climate factors could be easily examined at village of Garang, Hassan banda, Jangerizi banda, Kiridhand, Takht Nasrati and Yaghi Musakan from the tehsil. Close-ended questionnaires were used to collect cross sectional and time series data from household basis of availability of groundwater extraction facilities.

Sample size and sample design

A total of 1100 households had possible facilities for groundwater pumping and the Uma Sekaran table was used to determine a sample size of 285 households (Sekaran, 2006) and distributed into six villages through the proportionate allocation technique, explained in Equation 1 and Table 1.

$$n_i = \frac{N_i}{N} \times n \quad ...(1)$$

Data analysis

SPSS (v21) (Statistical Package for the Social Sciences) is computer software for data management and innovative analytics designed by IBM.

Statistical and econometric techniques

Empirical analysis: The mean groundwater levels were recorded from various aquifers to estimate the CC impact in the area. Various climate indicators were taken compared to past literature such as different rain patterns, decline in rain, rising temperatures, humidity and delayed seasons (Qureshi, 2005; Addaney *et al*., 2017; Nygren *et al*., 2020). Logistic regression analysis assessed climate change impact on groundwater aquifers (Li and Merchant, 2013) as in model Equation 2.

$$P = \frac{e^{(b_0+bX)}}{1+e^{(b_0+bX)}} \quad ...(2)$$

Table 1: *Proportional allocation for sampling distribution of respondents in selected villages.*

District	Union councils	Villages	No. of Households (Tubewells + Bore wells + Dugwells)	Sample size
Karak	Takht Nasrati	Garang	(3+155 +32) 190	49
	Mianki Banda	Hassan Banda	(7 + 118) 125	32
	Jahangiri Banda	Jangerizi Banda	(13 + 76) 89	23
	Hassan Banda	Kiridhand	(20 + 118) 138	36
	Takht Nasrati	Takht Nasrati	(5+365 +2) 372	97
	Jahangiri Banda	Yaghi Musakan	(21+165) 186	48
Total			1100	285

Source: *Union council office, Shanawa Gudi Khel.*

The binary regression model was specified in the functional form, given as:

$$P_i = E(\{Y = 1|X_i\}) = F(Z_i) = F\left(\propto + \sum_{i=1}^{n} \beta_i X_i\right) \quad \ldots.(3)$$

(Cumulative logistic density function).

Where; $$Z_i = \propto + \sum_{i=1}^{n} \beta_i X_i + \varepsilon_i \quad \ldots.(4)$$

also, $$P = \frac{e^{(Z_i)}}{1+e^{(Z_i)}} \; and \; (1-P_i) = \frac{1}{1+e^{(Z_i)}} \quad \ldots.(5)$$

The odd ratio was given by:

$$\frac{P_i}{1-P_i} = e^{Z} \quad \ldots.(6)$$

Taking the natural logarithm of Equation 3-9, we obtained:

$$Z_i = ln\left(\frac{P_i}{1-P_i}\right) = \propto + \sum_{i=1}^{n} \beta_i X_i + \varepsilon_i = L_i \quad \ldots.(7)$$

The model equation was presented in its simplified state as follows:

$$log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_i X_i + \epsilon_i \quad \ldots.(8)$$

The functional form of the model for logistic regression to find the impact of climate change on groundwater recharge system in study area becomes as follows:

$$log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 D_1 + \beta_2 S_2 + \beta_3 W_3 + \beta_4 P_4 + \epsilon_i \quad \ldots.(9)$$

Where; log (p/1-p) is probability of climate change impact or no impact on the Groundwater level, β_0 is constant, β_i represents the coefficients, P_R shows different rain patterns, Q_R is declined rain quantity, T_3 is the rising temperature, H_4 is Humidity and D_5 represents Delayed seasons. Figure 2 explains hypothetical framework practiced in study.

Climatic factors

The main climatic factors available in the area were (1) Shifting rain patterns showing a directly positive impact on the groundwater, (2) Declined rainfall which is the most important source of recharge for groundwater as rainfall is the merely foundation to revive the subsurface water (Shakya *et al*., 2019a, b), (3) Rising temperature is the second known indicator of climate change responsible for increasing rates of evaporation and transpiration, causing negative impact, (4) Humidity is the vapors content present in the air which means less moisture content in the soil to percolate deep in the soil, and (5) Delay in seasons which maybe either way have an impact on the groundwater. In winter seasons the groundwater levels drop due the freezing effect while in summer season the ice reserves melts and the groundwater level rises.

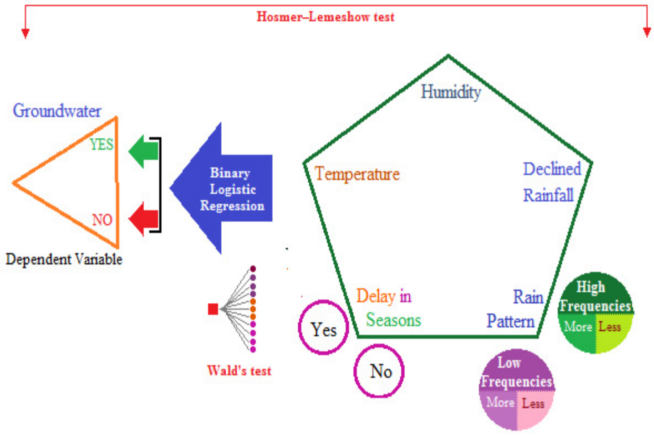

Figure 2: *Hypothetical Framework practiced in study.*

Results and Discussion

Climate change impact and groundwater: logistic regression analysis

Diagnostic tests: The Hosmer–Leme show test was used as goodness of fit to test the combined significance effects of the explanatory variables which were used in the study to explain or predict the climate change impact on ground water table. Table 2 revealed that the estimated p-value was 0.000 for the chi-square of Hosmer–Leme show which indicated that the probability to accept H_0 is zero and accepting H_1 which means there is combine significance effect of the explanatory variables in the study to predict climate change impact on groundwater table. Wald test (also called the Wald Chi-Squared Test) was a way to find out the significance use of explanatory variables in a model. Table 3 shows that the estimated p-value was 0.000 for the Wald chi-square which indicates the probability to accept H_0 is zero, where H_0 shows that their variable is significance effect of the explanatory variables in the study model.

Table 2: *Goodness of fit for the estimated model.*

Goodness of fit	Chi-square	Df	Sig.
Hosmer–Lemeshow chi 2	391.84	24	0.0000

Table 3: *Wald chi-squared test for the estimated model.*

The wald test	Chi-square	Sig.
Wald Chi-squared test	173.89	0.0000

Estimated coefficient and its discussion

Table 4 reveals 72.96 percent of variance in the dependent variable because of climatic factors. The Likelihood ratio value revealed the overall combined effect of these factors to be significant. Somehow, the individual effect of humidity was found statistically insignificant at 5%. The decline in rainfall and temperature was found to be statistically highly significant while other factors like decrease in rainfalls with low frequencies and delay in seasons were also found statistically significant at 5%. The finding reveals the status of rain pattern was directly related to groundwater decline for the decrease in rainfalls with low frequencies in the study area as compared to decrease in rainfalls with high frequencies. The Table 4 explains an increase in rainfall pattern of decrease in rainfalls with low frequencies will increase the decline in groundwater by 2.21 feet. The occurrence of such scarce rainfall events in the study area is being increasing the chances for declining of groundwater in the study area. Heavy rainfalls are needed to increase the amount of water seeping into the aquifers. Similarly, Addaney *et al.* (2017) and Olaniyi *et al.* (2013) also claimed the same results in their study about climate change contribution increases droughts, floods, and drying up of lakes because of erratic rainfall patterns. The declining rate of rainfall is highly significant. The finding reveals that a decline in rainfall increases the chances of climate change impact on groundwater table by 6.08 feet. Rainfall has been the only possible groundwater recharging resource for years in the study area as the area lacks surface water resources. Further, Qureshi (2005) worked on Climate Change and Water Resources Management in Pakistan which showed that global climatic changes have increased frequency of droughts in 4 out of 10 years in the last decade with 50% lower rain during 1997-2000. The table also shows the rising temperature is highly significant and reveals that rising temperature increases the chances of a decline in groundwater by 4.19 feet. Temperature increases evaporation and transpiration rates in plants, thus increasing the demand for groundwater. Moreover, Jyrkama and Sykes (2007) reflect the study as they find that global warming was resulting in the increase of evapo transpiration rates as distinguishing the sequential and spatial climate change impact on groundwater recharge. The delay of seasons has an impact on the timely recharge of groundwater, resulting in ground water decline in the study area. The findings revealed a delay in seasons positive and statistically significant. The occurrence of delay in season once increases the chance for groundwater decline by 1.67 feet. Nygren *et al.* (2020) conquer the same results through statistical tests explaining a major reduction in the annual groundwater recharge as a result of seasonal shifts among the median depths. The study suggested that such changes occurring over longer timescales were decreasing groundwater storages in Fennoscandia. Various studies also revealed similar effects in areas with mainly local aquifers in large parts of northern Asia and east of the Rocky Mountains in North America (Fan *et al.*, 2013; Beck *et al.*, 2018).

Table 4: *Parameter estimates of logit model for CC impact on groundwater decline.*

Groundwater decline	Coef (β)	Std error	Z	P>z
Rain Pattern (decrease in rainfalls with low frequencies)	2.208271 9.09972*	0.8820647 8.026764*	2.50	0.012
Decline in rainfall (yes)	6.084918 439.1839*	1.098736 482.5471*	5.54	0.000
Temperature (Rise)	4.191445 66.11824*	0.817446 54.04809*	5.13	0.000
Humidity (yes)	-0.3721738 0.6892344*	0.6722356 0.4933279*	-0.55	0.580
Delay in season (yes)	1.672147 5.323583*	0.6692887 3.563013*	2.50	0.012
Constant	-7.241117 0.0007165*	1.285208 0.0009209*	-5.63	0.000
Number of observations = 285 LR Chi^2 (5) = 173.89 Prob> chi^2 = 0.0000 Pseudo R^2 = 0.7296				

Source: *Field survey, 2022. (*) in 2nd column shows Odd Ratios and their respective standard errors in 3rd column.*

Conclusions and Recommendations

The overall climate impact was highly significant and caused 72.96% decline in groundwater. Further, it was revealed that the decline in groundwater was due to declining rainfall and the absence of alternative sources for groundwater recharge. The rising temperatures ministered a decline in groundwater by increasing evaporation and transpiration rates. Delayed seasons would cause delay in rainy periods which declined the groundwater due to water loss. Established upon the conclusion, climate sustainability and conservation of groundwater resources at the community level should be transcribed through best management practices for groundwater conservation. Public education and outreach are very important to play their role in public awareness and provide innovative and indigenous strategies for recovering groundwater against climate change.

The purpose of the study is to make specific and realistic suggestions and provide assistance to future researchers, policymakers, stakeholders and local as well as federal governance before they conduct a similar experiment or find a similar problem. Similarly, the main features of this study were to assist the Khattak locals and communities to overcome the water issues for lasting years and recover groundwater to its sustainable level.

Novelty Statement

This study focuses upon the impact of climate change on the groundwater aquifers as the study area is rainfed and lacks surface water resources. The recharge of the groundwater aquifers highly depend on rainfall, which is primary climate change indicator. Therefore, adverse behaviour of climate change has shown severe decline in the aquifers at District Karak.

Author's Contribution

Ahmad Noor: Principal author, did research, analysed and interpreted data, compiling, presenting and wrote the manuscript.
Malik Muhammad Shafi: Major supervisor assisted in acquisition of data, helped in drafting of the manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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