Spatio-Temporal Variations of Ground Water and Quality Analysis: A Case Study of Indus Basin Aquifer System; Lahore Region

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Abstract- Groundwater depletion is one of the most alarming perspectives of this century. It has become the global problem and South Asian Region is standing at top of the list. The significant effects of groundwater depletion have been observed in both urban and rural areas of South Asia which are suffering from this inappropriate change. In the context of groundwater depletion in Lahore city, which is part of Indus Basin Aquifer System (IBAS), this study has considered GIS and Remote Sensing techniques for precise detection of land use change and its impacts on groundwater resources in the Lahore region. The built-up area of Lahore district was 395.53 sq.km in 2000, increasing to 556.95 sq.km in 2014, which reflects major change in land use during this period. The increase in built-up area was in the south-east, south and south-west directions, while in northern side it was bounded by River Ravi. Increases in population and mass migration from rural to urban areas and change in land use have had a disastrous effect on the groundwater resources of the region. The water table has dropped from 15 meters to 35 meters during last three decades. In this study, the future stress on groundwater was assessed by using first order Markove chain model. The results of water quality and its spatial aspects were also evaluated for resource planning. The results of this study have shown that TDS (143.358-368.141 mg/l), pH (7.23-8.033), Temperature (30.734-34.698^{0}C), EC (160.235-1039.99 mS/cm) and Turbidity (0.048-1.872 NTU) were rigorous in nature in the north-east and north-west directions of the Lahore region. The continuous overexploitation of groundwater to meet the consumption requirements has resulted in declining groundwater level and deterioration in groundwater quality due to imbalance between exploitation and recharge rate.

Keywords: Indus basin aquifer system, ground water quality, land use change, ground water mining, remote sensing.

I. INTRODUCTION

Groundwater is a life sustaining resource that must be maintained at global level by determining the capacity of an aquifer along with safer drinking quality standards [1,2]. However, rapid growth of population is putting a continuous pressure on the overall water balance and, therefore, has resulted into the faster depletion of majority of the ground water reserves in developing world [3,4 and 5]. Since, South Asia is a heavily populated region in the Indian subcontinent, development with least sustainable practices is a threat to its groundwater resources, particularly in terms of volume and contamination [6,7,8,9 and10]. Recently documented evidence about groundwater mining suggests that the heavy consumption is attributed to the poor irrigation, agriculture, and domestic practices. Globally, irrigation accounts for more than 70% of total water withdrawals and for more than 90% of total consumptive water use [11,12,13,14,15,16,17,18 and 19]. Ground water mining rate in South Asia is reported as approximately 54 km^3/year due to intensive irrigation [20], with continuous decline and mainly due to the rice crops [9, 21 and 16]. The Indus Basin Aquifer System (IBAS) of northwestern India and Pakistan is the second-most overstressed basin of the globe (UC Irvine/NASA/JPL-Caltech 2013), with the Indo-Gangetic regions contributing 25% of total global withdraw of groundwater [22]. The IBAS comprises of the upper Indus regions (Gilgit, KPK and Punjab) and the lower Indus region (Sindh and Balochistan). Intensive population growth in the Punjab region has created more groundwater problems.

A special case of the Lahore region was considered in this study. It is the capital city of Punjab province and the second largest city of Pakistan, with a population of more than 10 million. The aquifer in Lahore (Part of upper IBAS) is comprises of alluvial deposit and therefore has greater depth of water saturated zone. Groundwater mining problems are being faced by Lahore region as is the case in other

ISSN:1813-1786 (Print) 2313-7770 (Online)

densely populated regions of world. In this region, the groundwater system is overstressed due to rapid urbanization and industrial growth. Groundwater mining has been observed in this region over last three decades at a rate of more than 2 ft/year. Quantitative and qualitative evaluation of the groundwater reserves by using the modern technologies is a critical precursor to improving its management.

However, regional spatio-temporal patterns of the groundwater system seem difficult to estimate due to the various associated factors, i.e., recharge flux, base flow, volumetric assessments, economical parameters, subsurface anomalies, water demand and supply, chemical, physical, and biological parameters [1], and other quantitative and qualitative variables. Modern techniques have established profound relationships between safe withdrawal, natural replenishments, and urbanization impacts [23,24 and 25]. A successful example is the application of geospatial analyses for the evaluation of spatial and temporal information of urbanization and groundwater system [26,27,28,29,30 and 31]. These geospatial tools, which are based on satellite image manipulation, are sufficiently precise for estimating any groundwater system under specific conditions e.g. GRACE estimation [31].

This study focused on land use change analysis, ground water quantity (using historical records of water table) as well as quality issues using geospatial tools to the groundwater system of Lahore. More precisely, (1) quality parameters were embedded to the geospatial framework; (2) integration of land use changes and thematic mapping was performed to identify the direction of demographic growth (3) water table declining pattern was analyzed using historical records (4) quality of groundwater was estimated with its spatial pattern using thematic mapping.

II. Study Area

Lahore is the capital of Punjab province and is also recognized as the 2nd metropolitan city of Pakistan (Figure 1). It is bounded on the north and west by Shaikhupura district, on the east by Wagha, and on the south by Kasur district (31°15ˋ– 31°45ˋ N and 74°01ˋ 74°39ˋ E). The total area of Lahore is about 1,772km^2, with population of 11,126,285 (2017 census). An annual average population growth rate since 1998 is 4.07% [32]. The climate of Lahore city is consisting of extremely hot summer and cold winter seasons and falls under category of hot, semi-arid climatic zone of Pakistan. Dust storm in summer and monsoon season starting from late June to September is responsible for heavy rains in Lahore city, maximum rain was observed 177 mm in September 2014 [33]. The highest temperature of 48.3°C was recorded on 30th of May 1944, while the lowest temperature of -1°C was recorded on 13th of January 1967.

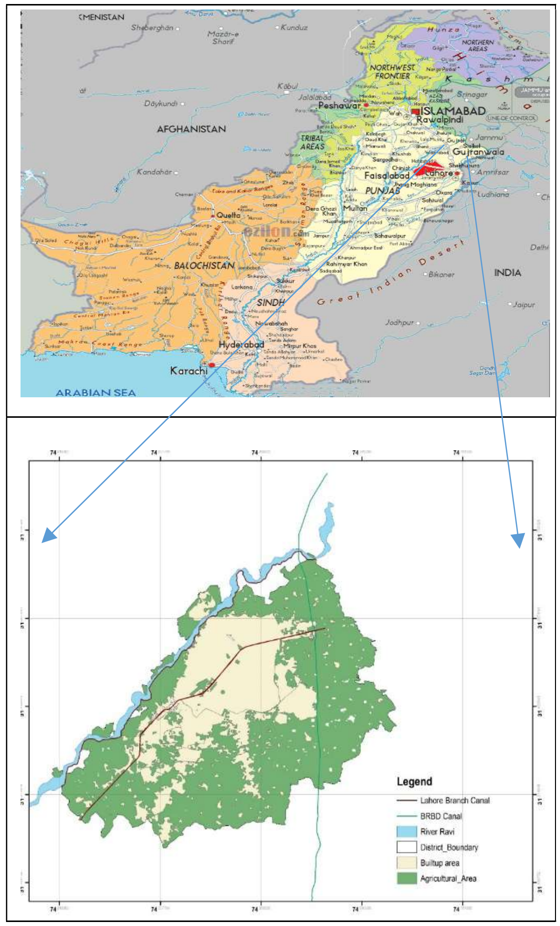

Figure 1. Location of study area (Lahore city)

III. Methodology

3.1. Data

A three step methodology was carried out for water table depth analysis, land use change detection and water quality characterization. The study further incorporates water table level by analyzing the locations of tube wells in the raster maps to reveal the urbanization impact during last 20 years. For change detection of urbanization; the 10-year interval was chosen to identify the substantial change in land use because it typically requires at least one decade to change from an agricultural area into a more heavily populated urban area. Raster cell identification method was employed to detect the land use changes as it gives the reliable results. Finally, the groundwater level data was used to draw contour maps for identifying depletion rate.

3.2. Land use change detection

ERDAS Imagine (application of remote sensing) embedded with graphic editor capabilities was used to detect land use change. To meet the required objectives, Landsat satellite imageries have been

ISSN:1813-1786 (Print) 2313-7770 (Online)

used. The satellite images of 16th of March, 1990; 11th of march, 2000; 7th of march, 2010; and 21st of march, 2015 were used, respectively. Further interpolation as reclassification and raster cell identification to estimate the differential change in land uses was done in ERDAS IMAGINE framework by using the classification algorithms. After classification, raster cell identification techniques were applied to find the expansion of urban area and reduction in vegetal cover.

3.3. Ground water variations

To analyze the groundwater depth variations, formal sampling (Random samples collection) was done with GPS to get accurate coordinate of these sampling points. The water table depth and fluctuation data from 1991 to 2010 was obtained from water and sanitation authority (WASA) Lahore, Pakistan. The particular focus was given to the pre-monsoon period because maximum recharge takes place in this season. For groundwater depth fluctuation, simple surfer interface was used in ARC GIS software. To predict further changes in groundwater depth, Markove first order stationary model was used which provide the satisfactory results for future prediction given in Equation 1.

$$D_{j+1} = \bar{D} + \rho 1\left(D_j - \mu_D\right) + \bar{D} Sd_D\left(\sqrt{1-\rho 1^2}\right) \quad 1$$

Where D_{j+1} new water table depth, $\bar{D}$ is a depth, D_t is preceding depth value of given month, Sd_D is standard deviation and $\rho 1$ is LAG1 correlation.

3.4. Water quality evaluation

To investigate water quality parameters, in-situ sampling methodology was adopted and the samples were tested in the laboratory to evaluate different physico-chemical quality parameters. The random samples from different locations of Lahore region were collected with GPS location, so that their spatial interpolation could be performed. After laboratory testing, spatial interpolation technique Kriging (which is most widely used) was used to prepare spatio-temporal maps of Lahore region.

IV. Results and Discussions

4.1. Indus basin aquifer system

Groundwater systems are dynamic in nature. The IBAS is the third most threatened example of this dynamicity. The whole Indus basin is known for its agriculture-based economy which is highly dependent on water. In IBAS, groundwater monitoring of water table depth measurements provides vital information about the hydrological stresses, groundwater recharge, storage and discharge. Long term systematic groundwater monitoring provides essential data needed to evaluate changes in the resources with the passage of time, to generate groundwater models and predict trends. These in turn help to design, implement, and monitor the effectiveness of groundwater management, protection, and conservation programs. Under natural conditions, groundwater systems are in dynamic equilibrium in which long-term average recharge equals to average discharge. When the pumping rate is larger than the total recharge, recharge is insufficient to support the pumping, and the groundwater storage is continuously used to balance the pumping rate. Under this scenario, groundwater levels will continuously decrease, and the groundwater storage will eventually be depleted.

4.2. Land use changes and urbanization in Lahore

This study revealed that the urban area of Lahore has increased with expansion of the city towards the south-east, south and south-west along with the major roads. The inverting relationship between three land use classes: agriculture, water bodies and urban area was investigated in this study. It was found that there is an increase in urban class while decrease in other two classes, i.e. agricultural area and water body. The further results indicated that the expansion of urban area was mainly distributed along both sides of Ferozpur, Riwind and canal roads. The urban expansion trends can be seen in the directions of south-east and south-west as mention above. As north and north-east sides of the city are blocked by river Ravi, while the area of district Lahore in east is restricted by Pak-India border, for this reason there is no urban expansion towards these sides. These natural barriers impose limitations on further urban expansions in those directions (Figure 2).

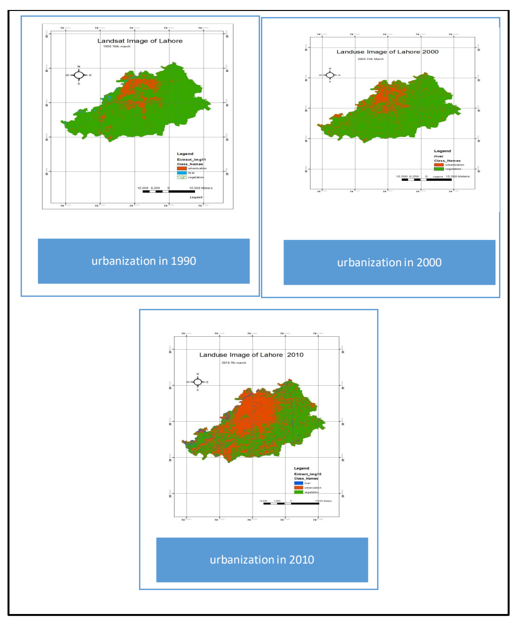

Figure 2: Land use change and urban expansion of city Lahore from 1991-2010

The results of literature survey revealed that the population of this region has grown up to more than 1.1 million. This population burden has put pressure for urban development, which ultimately changed the land use structure of Lahore city. This major growth of population occurred over the last three decades; in which it has increased from 6.4 million (According to 1998 census) to 1.1 million (2017 Census). The growth rate is 4.07% per year, and in response to population demands, the groundwater extraction rate has increased from 15 cusecs per square mile to 23 cusecs per square mile.

4.3. Groundwater and the city of Lahore city

The groundwater depth data records of Lahore revealed that the decrease in groundwater table was significant in Lahore city. In this study, only monsoon periods were evaluated (because in these months there are high rains in this region with favorable atmosphere of recharging by natural process). This includes the months of January, June, July, August, September and December. The major reason of this declining trend of groundwater in this region is heavy use of asphalts, population density and irrigation usage. Analysis of this data shows that in year 1990, the depth to groundwater level was 15 meters but after just three decades the depth to groundwater is now 35 meters (Figure 3).

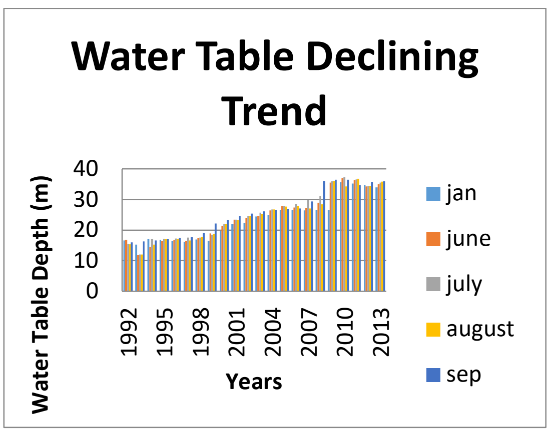

Figure 3: Water table depth variations of Lahore city

In this study it was also observed that the Lahore population has grown up to 1.1 million in the past three decades. However, groundwater resources have not grown to meet the growing demands of the population, consequently overexploitation of groundwater resources has occurred in these decades, leading to groundwater decline. In this study, tube wells were selected that were officially marked by the Water and Sanitation Authority (WASA) of Lahore. The maps of water table depth were prepared (based on data for 486 tube wells) for various period (1990, 2000 and 2010), indicating that excessive groundwater extraction formed cup shaped depressions in various towns of Lahore (Figure 4a,4b and 4c), which gradually attain equilibrium. Based on available data and field survey, tie change in depth to water table has been computed by using Arc GIS. The overall depth of the groundwater table varied within the range from 6-50 m in Lahore.

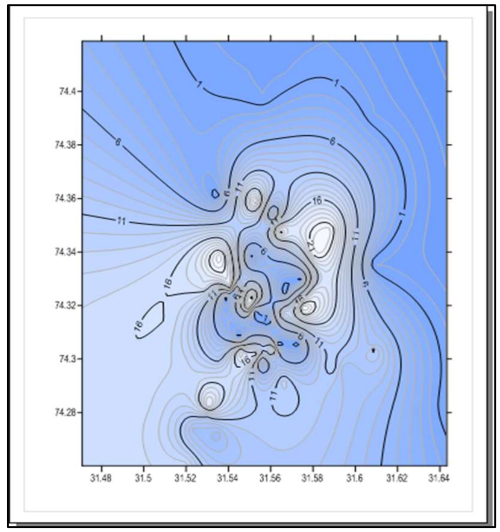

Figure 4a. Water table variation of 1990

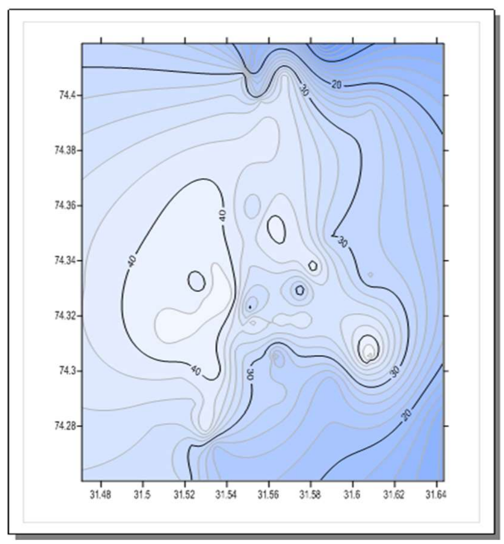

Figure 4b. Water table variations of 2000

ISSN:1813-1786 (Print) 2313-7770 (Online)

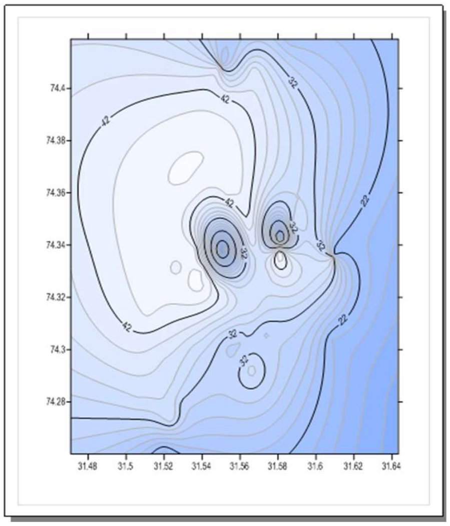

Figure 4c. Water table variations of 2010

The results of future extended ground water table depth time series showed declining pattern. The data was extended using Markove first order, although we cannot propose with surety that what will happen in future but our results confirmed that there will be an increase in ground water table depth and there is a need to take adaptive measures which can reduce pressure on ground water resources of Lahore city (Figure 5).

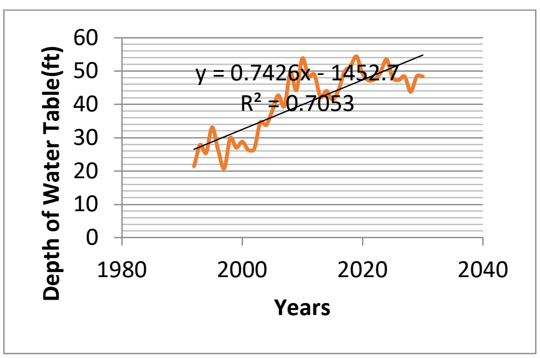

Figure 5. Future projected groundwater table depth of Lahore city

4.4. Groundwater quality analysis

The results of water quality testing revealed that different quality parameters such as pH, TDS, Temperature, Turbidity and EC are having slightly increasing concentration. The disequilibrium of these parameters is a future threat to inhabitants of this region. The main reason behind this quality deterioration of groundwater is addition of industrial pollutants. Furthermore, the increasing population has also been generating increasing waste, which is dumped deep into the earth and flushed with water from the sewerage system, ultimately reaching the groundwater reservoir. Although water quality results are being meet by international quality standards at this time but if the situation continues, then it will result into deterioration of water quality in future. The results of Spatial analysis through geospatial techniques found higher concentrations of water quality parameters in the northwest direction. The total dissolved solids (TDS) have value ranging between 143.358-368.141 mg/L (Figure 6a) concentrated in north west and slightly moving to north east while pH value was varying between 8.033-7.23 (Figure 6b) and this is almost equally distributed over the region. Turbidity was found in the range of 0.048-1.872 NTU, which is within defined limits of the World Health Organization (WHO). Spatial expansion of turbidity is in direction of north west and south east (Figure 6c) while temperature variation is also in western part of Lahore region ranging between 30.734-34.698 NTU (Figure 6d). Finally, it was observed that electric conductivity (EC) was also distributed spatially in north side of Lahore region ranging between 160.235- 1039.99 mS/cm (Figure 6e). Although, epidemiological studies do not identify direct effects of drinking water, in the long run it may be harmful to local populations.

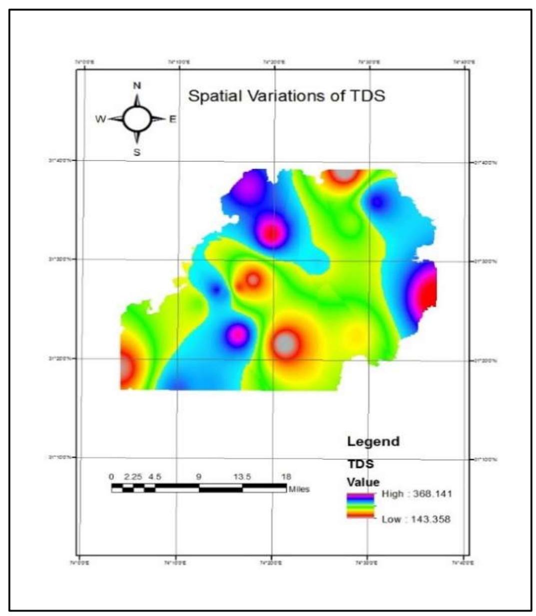

Figure 6a: Spatial variations of TDS in Lahore city

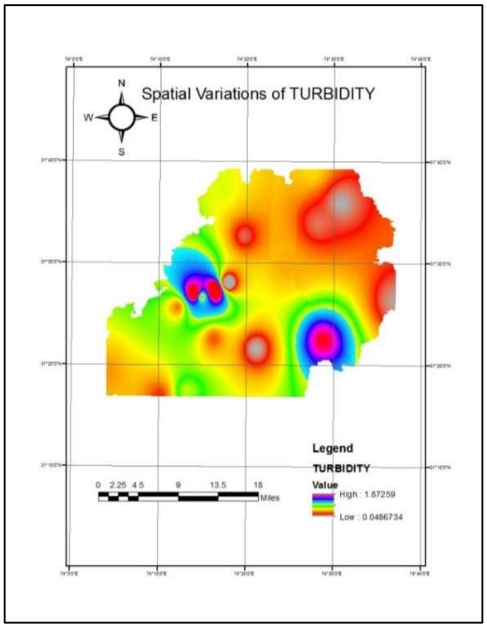

Figure 6b: Spatial variations of pH in Lahore city

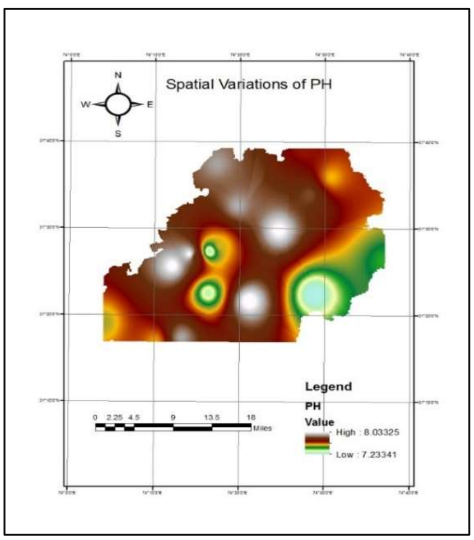

Figure 6c: Spatial variations in groundwater turbidity of Lahore city

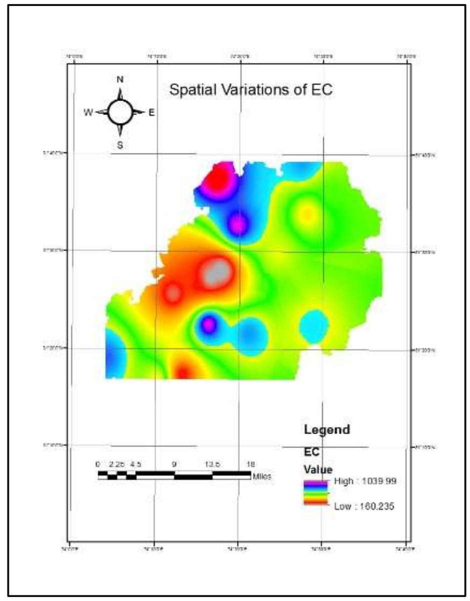

Figure 6d: Spatial variations in groundwater temperature of Lahore city

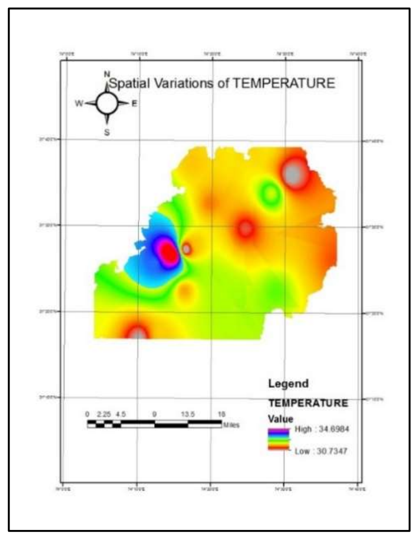

Figure 6e: Spatial variations in Electric Conductivity of groundwater of Lahore city

V. CONCLUSIONS

We have found a pattern of declining groundwater level and quality in certain directions. The future projection is that this pattern will continue. Groundwater is already being mined, i.e., withdrawals exceed recharge, and groundwater levels can be expected to continue to decline further. Besides affecting any remaining groundwater dependent ecosystems, declining groundwater level means that pumping costs increase. Increasing pumping costs means that water will become less available (more economically scarce) for at least some water users. Additionally, the predicted continuous decline in water quality will have detrimental impacts on the population and/or require additional water treatment, which is expensive, potentially increasing the cost of water delivery. Increasing the cost of water delivery again will decrease water availability, particularly to the poor community, resulting in more water scarcity. Despite of the population growth, there is a need to address the decline in groundwater levels to avoid increasing levels of water scarcity and increasing health risks to the population. This requires greater awareness of the problem, and greater policy and community action. The big opportunities lay in reducing water wastage and in increasing the water supply and efficiency of water use in agriculture and urban areas.

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Paper Titled: Spatio-Temporal Variations of Ground Water and Quality Analysis: A Case Study of Indus Basin Aquifer System (IBAS) Lahore Region.

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Sr.#	Author-s Full Name	Contribution to Paper	Signature
1	Mr. Muhammad Waqar (Main/principal Author)	Proposed topic, basic study Design, methodology and manuscript writing	M. Waqar
2	Prof. Dr. Sajid Rashid Ahmad (2nd Author)	Spatial mapping and interpretation through GIS	
3	Prof. Dr. Akhtar Ali Malik (3rd Author)	Literature review & Referencing, and quality insurer	
4	Prof. Dr. Irfan Ahmad Shaikh (4th Author)	Data collection and Statistical analysis	