GEOGRAPHIC INFORMATION SYSTEM AND MODELING APPROACH FOR GROUNDWATER SYSTEMS OF RECHNA DOAB, PAKISTAN

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ABSTRACT: Excessive groundwater pumping in Rechna Doab has caused a depletion of aquifer body. Efforts were made to identify the ground flow dynamics and recharge sources of Rechna Doab. Finite difference model technique was used to study the groundwater system under steady state. Visual MODFLOW 2000 was used to steady state simulation of study area. Simulation of groundwater flow over an area of about 35,217 km^2 with a uniform grid size of 2500m by 2500m was done. Study area was divided into the grid of 138 rows and 100 columns. The seepage losses from canals, horizontal flows, recharge from precipitation and irrigation return flows were put to develop conceptual model. Discharge of canals, evapotranspiration and precipitation data was collected from local government agencies. Boundary conditions, hydraulic parameters and data of 50 observation wells were applied for model calibration. The zone budget study under steady state simulation showed that the total direct recharge to the aquifer was 645.48 MCM and total drought of the aquifer was 645.49 MCM. Based on results it was concluded that model was more sensitive to hydraulic conductivity and recharge parameters.

Keywords: Rechna Doab, zone budget, groundwater modeling, water balance and steady state simulations

(Received 21-11-2014 Accepted 23-11-2016).

INTRODUCTION

Groundwater is a vital natural source. Modeling techniques have been developed to study groundwater under natural conditions (Todd, 2005). In Pakistan the climate ranges from arid to semi-arid so average rainfall and surface water supplies are not enough to meet water demand. Additional water demand is met by groundwater extraction. The fresh water extraction from aquifer causes the saline water intrusion which is an irreversible process (Khan *et al*., 2003 and Ahmad, 2002).

Water scarcity is a major hindrance in sustainable agriculture development and productivity all over the world. During 1900 to 1995 the demand of groundwater increased six times i.e., twice the rate of population growth (Jehangir *et al.*, 2002). By 2025 the two third of world population will be living under water shortage conditions. In Pakistan the groundwater withdrawal is 30% of the total water demand (Khan *et al.*, 2003 and Aslam, 1997). In developing countries like Pakistan groundwater has emerged as a center of agriculture economy. Groundwater pumping at faster rate has been practiced in most of the agricultural areas than the rate of recharge, hence disturbing the groundwater level of the area (Ahmad, 2002). Therefore groundwater management is necessary for sustainable development.

Land use, soil characteristics, surface water and environmental issues are directly related to the groundwater systems. GIS technology has provided an efficient tool to deal with the large amount of datasets (Ashraf, 2008).The geographic location of Rechna Doab is between 71' 48' to 75' 20' E and 30' 31' to 32' 51' N. The area is bounded by river Ravi on eastern side and River Chenab on West. The total geographical area of Rechna Doab is about 2.98 million hectares having 2.3 Mha of irrigated and cultivated area. Temperature ranges from 21- 50^{o}C in summers during the months of April to October. In winter season it expands from December to February with temperature range of 7- 27 ^{o}C. Geographically Rechna Doab can be placed in semi-arid region. The area shows a great regional variation in precipitation, as the precipitation rate decreases in southward direction of Doab. The average rainfall at North station is 1046mm and in South it is only 276mm. About 72-76% of the annual rainfall occurs in monsoon period during the months of July to September (Jehangir *et al.*, 2002).

Pre-cambrian metamorphic and igneous rocks form the basement rock of the Rechna Doab. These rocks are known as Kirana Hills and comprise of the central part of the Doab running longitudinally along the width of Doab. In the upper part of Doab, the alluvium deposits are of gray and grayish brown color comprising clay, silty clay, silt and fine to medium sand. Coarser sand and gravel is absent. Small clay lenses are found at local level (Rehman, 1997). In southern part of doab coarser sand is found while clay lenses are localized. The heterogeneous nature of the lithology makes the aquifer body transmissive in nature (Khan *et al.*, 2003). In the central part of Doab, the homogeneity of lithology is disturbed by scattered bedrock. Bed rock replicates a sharp decline in upper Rechna Doab where there was no bed rock found up to the depth of 460 meters in a well drilled in Sheikhupura (Aslam, 1997). Buried ridges separate the Rechna Doab into two ground water basins. Thick clay lenses are not dominant in the area, therefore aquifer is highly porous and has the ability to store and transmit water efficiently.

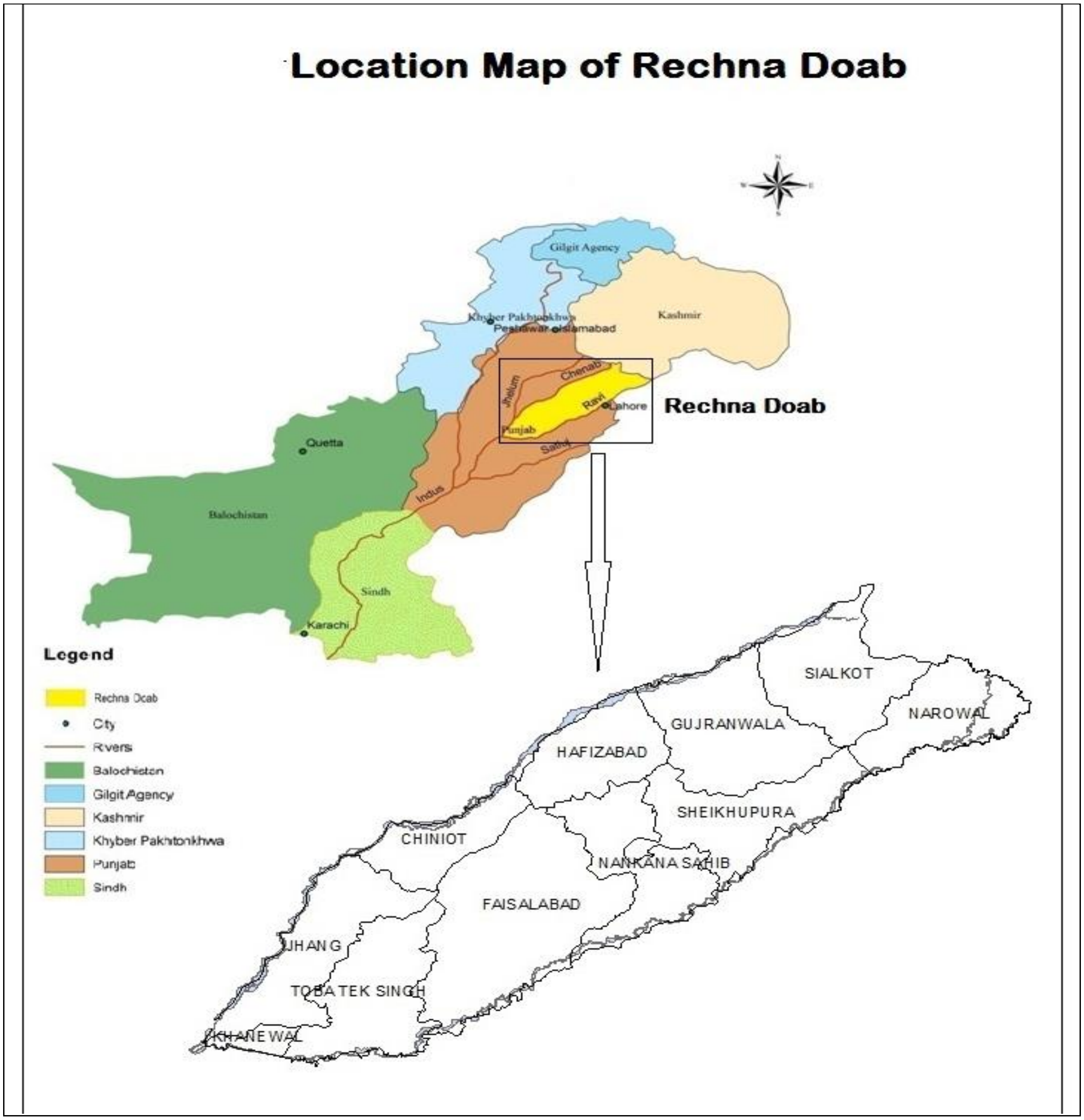

Figure 1. Location Map of Study Area

In upper part of Doab the porosity of aquifer ranges from 35 to 45 percent with specific yield of 14%. The horizontal conductivity values of the area are greater than vertical conductivity due to presence of clay material in vertical direction. The average value of hydraulic conductivity in horizontal and vertical direction is 1.2×10^{-3} m/day and 1.5×10^{-5} m/d respectively (Benenett *et al.*, 1967). The specific yield is 0.15 and 0.06 in sand and clay layers respectively as the clay lenses, silt, and silty clay forms the 25 to 35% of the whole alluvium deposit and sand forms the remaining 65 to 75 % part of the alluvium making aquifer more transmissive. The groundwater is unconfined and lateral permeability is much greater than the vertical permeability, due to presence of clay lenses (Mundorff *et al*., 1976).

The rivers Ravi and Chenab are natural hydrological boundaries of Rechna Doab Fig-1. The flow of both of the rivers is controlled by six headworks or barrages; four on river Chenab and two on river Ravi. These barrages control the irrigation flow of Rechna Doab and other nearby regions of Indus Basin (Khan *et al.,* 2003). Upper parts of the Rechna Doab have sufficient quantity of good quality water along the flood plains of both Ravi and Chenab rivers. Central and lower Rechna Doab earns poor quality water at the tail ends canal system (Aslam, 1997).

METERIALS AND METHODS

Visual MODFLOW and ArcGIS9.3 were the softwares used in present ground water modelling. Visual MODFLOW was used for simulation while ArcGIS9.3 was handy in digitization of different maps and DEM processing. The first step involved in the processing of Digital Elevation Model (DEM) for calculation of elevation of study area from the sea level. For this purpose DEM was used. Raster to vector conversion tool was used from Arc GIS 9.3 to convert the raster data (DEM) to point data(Lo and Yeung , 2003). The point data was re- projected from geographic coordinate system in projected coordinate system "WGS/ UTM Zone 43N" (McDonald and Harbaugh ,1984).

The elevation of different points of study area was incorporated to MODFLOW Visual 2000. Three layers of different thickness were developed; the Top layer (surface layer) was developed with elevation calculated from DEM. The second layer was designed with a difference of 50 meters depth from surface layer and third layer with difference of 200 meters. The model grid was developed from DEM data. The total area was divided into 138 rows and 100 columns with an area of 2.5×2.5 km^2.

Boundary Conditions were defined as Ravi river on the south eastern side and the Chenab on north western side of the study area (Khan *et al.*, 2003 and Rehman, 1997). There were different model inputs including precipitation, seepage through irrigation system, return flow, recharge through water courses and evapotranspiration were distributed on all the cells of model grid according to their geographic location. Model was run for steady state condition. Calibration was done for the model's independent variables to the simulated heads and calculated heads (Basharat *et al*., 2011 and Panagopoulos, 2012). The initial water level of about 50 wells evenly distributed throughout the study area was used for model calibration.

Model Inputs: The 20 % of the total precipitation of all the districts of study area (PMD, 1973-1997) was distributed in all the cells of the model grid (Basharat *et al*., 2011). The input parameter of seepage through watercourses involved twenty five percent of total discharge of all the 273 distributaries of the study area which became the part of groundwater recharge (PMU, 1999).

The total pumping in the study area was determined and its 20 % was distributed on all the model grid cells to input the parameter of return flows in the study area Table-1. The Study area was divided in four different zones of evapotranspiration.

The evapotranspiration data was collected from different stations of Pakistan Metrological Department Table-2. Different values of hydraulic conductivities were used in model put for different regions of the study area. The average value of K_h put was 35m/day while the average of vertical hydraulic conductivity was set as 1.6 m/day (Khan *et al.*, 2003).

Table-1 Model Input Parameters (PMD, 1973-97).

Sr. No	District	Average Rainfall (mm/year)	20% of average rainfall (mm/year)	Seepage (mm/year)	Return Flow (mm/year)
1	Narowal	693	138.6	87.05	66.26
2	Sialkot	749	149.8	87.05	104.81
3	Hafizabad	437	87.4	113.50	65.29
4	Gujranwala	581	116.2	83.73	104.89
5	Nankana Sahib	353	70.6	155.95	33.73
6	Sheikupura	476	95.2	84.99	38.50
7	Faisalabad	346	69.2	57.96	20.02
8	Jhang	248	49.6	96.57	26.49
9	T. T. Singh	255	51	122.03	27.22
10	Chiniot	336	67.2	50.26	53.44
11	Khanewal	166	33.2	70.01	57.80

Table-2 Different Evapotranspiration Zones in Study Area (PMD, 1973-97)

Sr. No	Evapotranspiration Zones	Evapotranspiration Rate (mm/year)
1	Zone 1 (Sialkot, Narowol)	1300
2	Zone 2 (Gujranwala, Sheikupura, Nankana Sahib, Hafizabad)	1400
3	Zone 3 (Faisalabad, T. T. Singh, Chiniot)	1500
4	Zone 4 (Jhang, Khenawal)	1600

RESULTS AND DISCUSSIONS

The method adopted to study steady state flow simulations was a one way approach (Pinder, 2002). Model was run on steady state conditions and was simulated. Model calculated heads, observed head, model simulated water elevation maps, water balancing components and water flow velocity maps were exported to identify the flow dynamics of the aquifer.

Model Calibration: Observed water levels of fifty (50) numbers of data points were used for calibration. The calibration of steady state, finite difference flow model of Rechna Doab was confirmed by root mean square value, normalized root mean square value and correlation coefficient of data (Observed Vs Calculated heads) obtained after model calibration Fig-2. A comparison was made at each well point between the calculated and observed head with a difference of less than 5%. The different calibration parameters are obtained by the calibration process. The observed normalized root mean square value was 4.9%. The Mean Residual Head (observed water level minus the simulated water level) was nearly about 2m which satisfied the simulated results of the model Table-3; (Chiang and Kinzelbach, 1998).

Groundwater Flow Direction: Groundwater velocity depends upon the lithology of the area and hydraulic gradient/ head of the area (Khan *et al.*, 2003; Domenico and Schwartz, 1990). Model generated flow direction map demonstrates a reginal flow from North to South Fig-3. The flow direction varied locally but overall trend remained the same. The arrow lengths were attributes of ground water velocity scale. It could be inferred from map that in upper part of Rechna (Sialkot, Narowal, Gujranwala) doab flow velocities were comparatively high as that of the lower doab (Faisalabad, Toba Tak Singh, Jhang and Chiniot).

Groundwater Elevation Trends: The groundwater elevation contours are good indictor to assess the contribution of canal system to the aquifer recharge (Vincent and Dempsey, 1991 and Bennett *et al*., 1967). Model generated ground water elevation contours have indicated that barrages, linked canals and main canals had major effect on recharge of aquifer. The downward curvature of contours at these points conformed the simulated recharge intensity. By comparing contour map with velocity map of the area it could be concluded that the velocity rate at specific points near barrages was also very high relative to other areas Fig- 4.

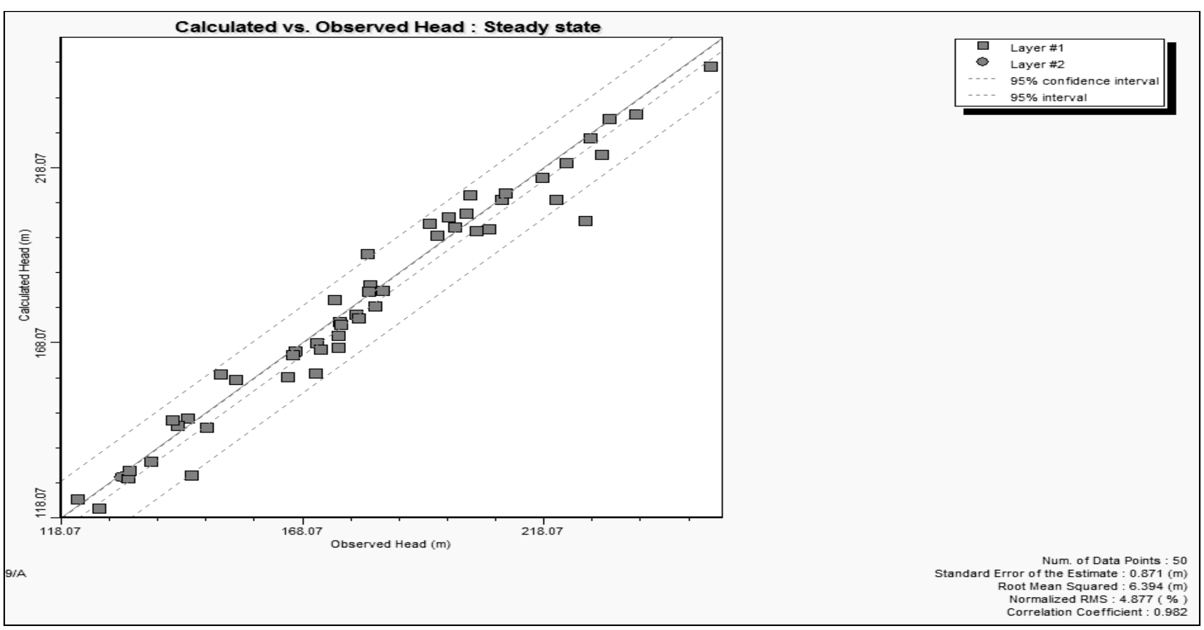

Figure 2: Comparison of Observed Vs Calculated Head at Steady State

Table-3: Steady State Calibration.

Root Mean Square (RMS)	6.4 m
Standard Error of Estimation	0.9m
Normalized Root Mean Square	4.9%
Correlation Coefficient	0.98
Max. Residual	-23.8m
Min. Residual	0.4m
Residual Mean	-1.9m
Abs. Residual Mean	4.8m

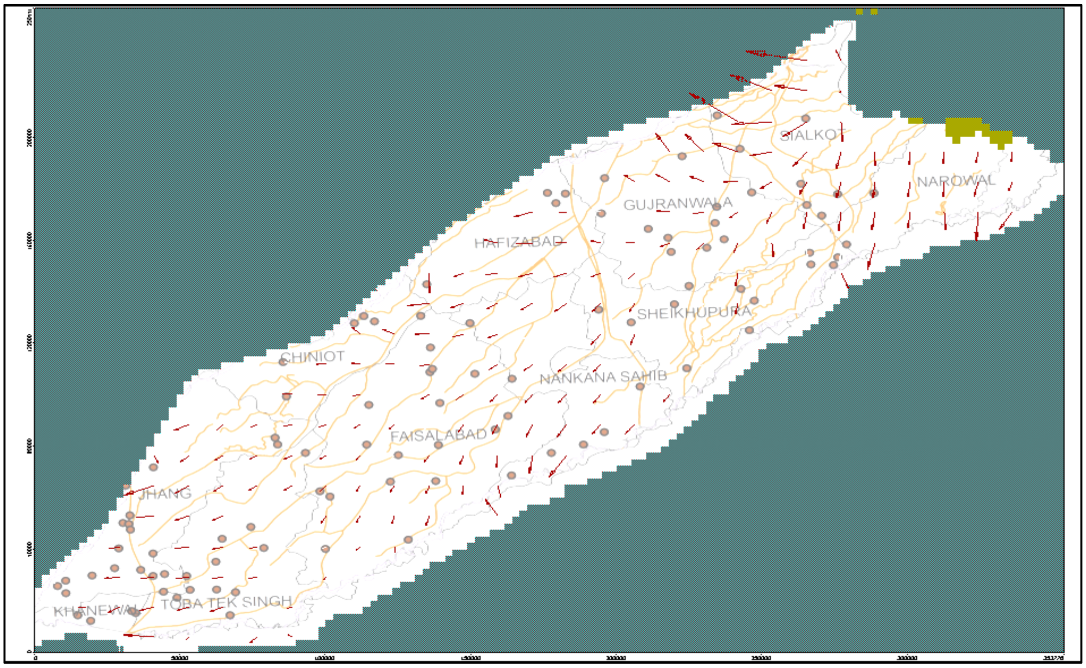

Figure 3: Velocity Map of Rechna Doab

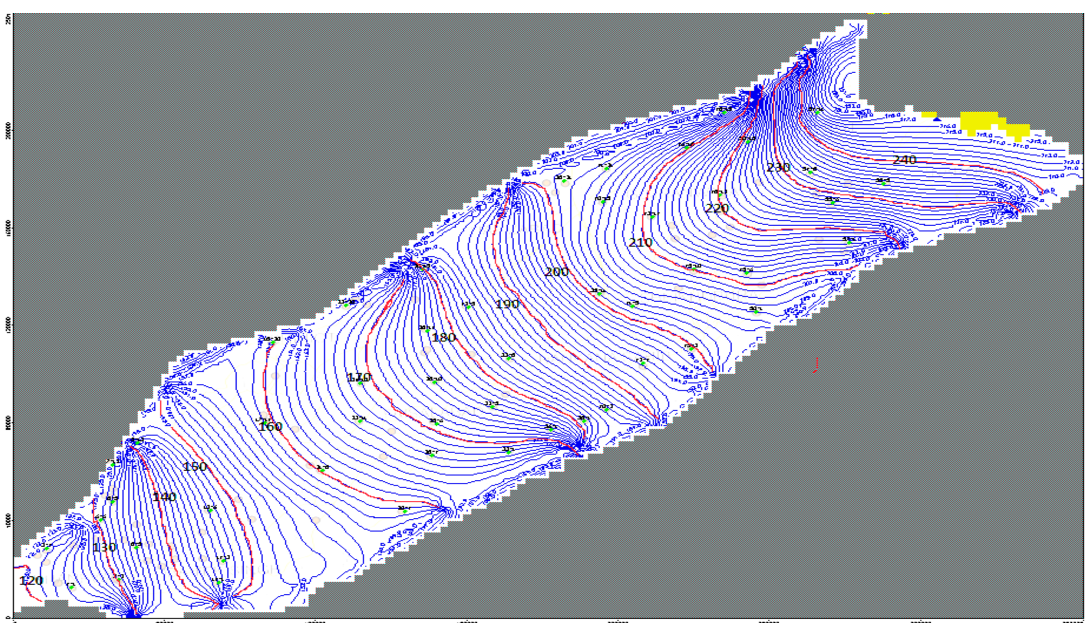

Figure. 4 Groundwater Elevation Contour Map

Water Balance Components: Results from the steady state model run demonstrated the major outflow of 5.62 MCM from rivers and evapotranspiration (8.3×10^{9} m^3). The river leakage was observed was 1.05 MCM which was one of recharge sources in the area Fig-5. Seepage through irrigation network could be considered as the main source of recharge to the Rechna Doab Aquifer area Table-4.

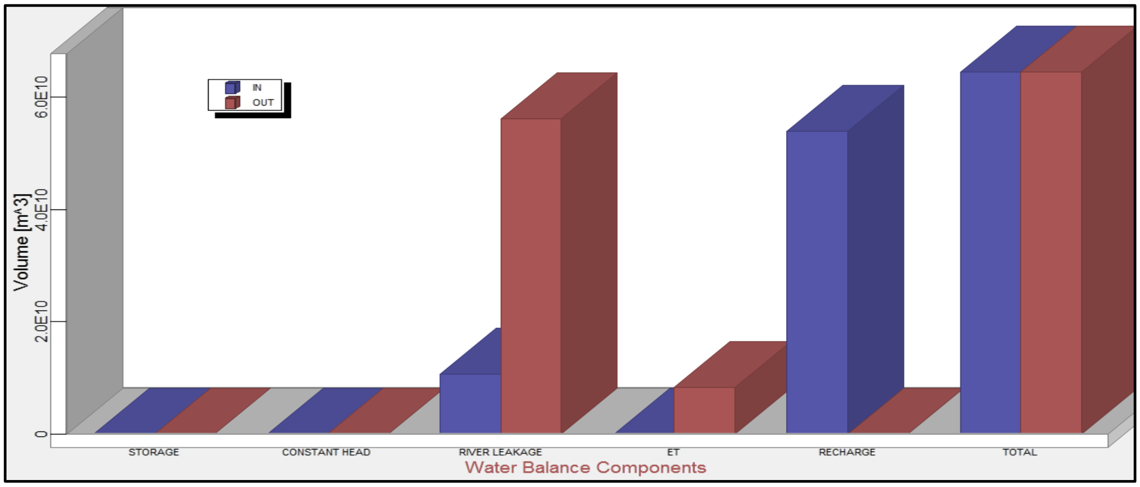

Figure. 5: Water Balance Components of Rechna Doab

Table-4: Water Balance of model domain.

Water Balance Component	Inflow (Volume: m^3)	Outflow (Volume: m^3)
Storage	0	0
Constant Head	0	0
River Leakage	1.1E10	5.6E10
Evapotranspiration	0	8.4E9
Recharge	5.4E10	0
Total	6.4E10	6.4E10

Conclusions: The mass balance components derived from simulation indicated a recharge of 645.48 MCM and the total drought of the aquifer up to 645.49 MCM. Model output designated irrigation system as the major source of aquifer recharge while river leakage as a mere role in recharging due to scarcity of water in the river Ravi. The future scenario of Rechna Doab could be predicted with the help of this study and thus helpful in groundwater management and water resources development.

Acknowledgements: Authors gratefully acknowledge the facilities provided by Dr. A.D. Khan, The Director General Pakistan Council of Research in Water Resources (PCSIR), Islamabad for his valuable contribution during this study.

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