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DELINEATION OF HYDROLOGICAL RESPONSE UNITS TO ESTIMATE WATER DEMAND OF CANAL COMMAND IN LOWER CHENAB CANAL USING GIS MODELING

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Limited surface supplies without considering crop water demand has created gap between water applied and its requirement. It results into extensive groundwater pump-age. It is therefore required to study crop water demand and supply at a specific hydrological unit level. In the current study crop water supply and demand was assessed in command area of two main distributaries (Killianwala and Mungi) of Lower Chenab Canal (LCC) based on unique hydro-geology. Three parameters including land use, soil type, and topography were used to develop Hydrological Response Units (HRUs) using Soil and Water Assessment Tool (SWAT) model and GIS. Forty-one and forty-two HRUs were developed for Killanwali and Mungi distributaries, respectively. The daily reference crop evapotranspiration (ET_o) for the canal commands was estimated using CROPWAT 8.0 model for the period of six years (2007-12). The crop water requirement was estimated using ET_o, crop coefficient (K_c) and cropping period at HRU level. The water shortages observed were more than 50% at both distributaries. Results showed that the maximum water shortfall at Killianwala and Mungi distributary were 4.1 MCM/Year and 4.9 MCM/Year, respectively. It was concluded that canal water supplies should be scheduled with the consideration of water requirements of each zone. Eventually, a shift from supply based to demand-based irrigation is highly recommended.
Keywords: Surface water, hydrological response, canal water, lower Chenab canal.

INTRODUCTION

Surface water is a major source of agricultural activities in Pakistan. About 95% of total available water is being used in agriculture sector while remaining is meant for domestic, industrial and ecological use (Bhatti *et al*., 2009). Agricultural share of fresh water is shrinking due to increasing demand of fast growing population that is resulting in urbanization and industrialization. It is creating really an alarming situation for such a developing country which requires sustainable use of water for crop production. To ensure the sustainability of water for crops, there is need of appropriate management of water resources (Shabbir *et al*., 2012).

During last decade, decrease in rainfall and rise in temperature have negatively impacted the water availability and thus caused water shortages in the country (Bates *et al*., 2008). Per capita water availability has already been declined from 5,260 m^3 in 1951 to 1038 m^3 in 2010 (WAPDA, 2011). By 2025, Pakistan will be facing severe water shortages (IWMI, 2000). This situation has caused severe pressure on groundwater that results in over exploitation of groundwater in large areas and in some areas soil salinity issues are also becoming prominent due to application of poor quality groundwater.

Another reason is that there are number of operational problems associated with canal irrigation system in Pakistan. It results in huge quantity of water losses during its conveyance. These water losses result in constrained water supplies of canal water. These losses have their major impacts on supply and demand management system (Arshad *et al*., 2009).

This shortage of water lead to lower crop productions in both irrigated and rain-fed areas. The irrigation system of Pakistan was designed for cropping intensity of 60 to 70% that has been increased up to 200 percent (WAPDA, 2011), which is approximately three times more than the designed capacity. On the other side, the agricultural water use efficiency is also very low i.e. over all system efficiency is 45% (Bhatti *et al.*, 2009) thus widening the gap between water demand and supply. It is expected that the supplementary irrigation deliveries will be only from saving of water (Tariq and Kakar, 2010).

Inefficient use of water and land resources is due to unavailability of consistent information on the exact water demand of cereal crops (Hafeez and Khan, 2005). Therefore, quantification of spatial and temporal crop water requirement is needed at a scale that is compatible with Pakistan's farm settings. Mostly, crops are being grown based on soil, climate and water availability to obtain maximum yield.

This situation requires area specific information on water demand and supply so that a comprehensive water management plan can be prepared and adopted. However, estimation of water supply and demand at a spatial scale is difficult to attain without use of Remote Sensing (RS) and Geographic Information System (GIS) modelling techniques that help to spatial map cropped areas.

In this study, an attempt was made to spatially map irrigated area of a canal command into unique combination of land use, soil and topography using Soil and Water Assessment Tool (SWAT) and GIS, commonly known as Hydrological Response Units (HRUs). These HRUs are analyzed and irrigation water supply and demand are calculated at HRU level on the recommendation of this study. The gap between water demand and supply was assessed and suggestions are provided for water managers for suitable management of water and land resources at regional scale.

MATERIALS AND METHODS

***Study area*:** Lower Chenab Canal (LCC) is one of the major canal command systems in Punjab, Pakistan. Two distributaries of LCC (Killianwala and Mungi) were selected for current study. Geographical location of the study area is between 30°34′N to 31°47′N latitude and 72°10′E to 73°40′E longitudes at an average elevation of 184 m above mean sea level. Killianwala and Mungi distributaries receive water from Burala and lower Gogera branch of LCC, respectively. The command area of Killianwala and Mungi distributaries is calculated as approximately 78,000 acres and 56,000 acres, respectively. The crusts of this area are built of alluvial soils which were transported by floods and settled here (Jehangir *et al*., 2002).

***Cropping pattern*:** The major crops of this area are wheat and fodder in *rabi* while cotton and rice in *kharif*. Sugarcane, vegetables and orchards are also being grown at large tracts. Major crop rotation is wheat-cotton at 10.23% of area, wheat-rice (9.65%), wheat-maize (3.40%), wheat-fodder-mix (19.26%) and sugarcane-cotton-mix at 18.24% of total area of the two distributaries (Tahir, H.M., 2012). Water requirement of these crops varies and a competition of water use can be observed due to varied crop water requirement of different crops. Most of the water requirement is met through surface water however groundwater is also being abstracted heavily although the quality of groundwater is not fit for irrigation.

***Climatic data*:** Climatic data (2007-12) was obtained from meteorological station located at University of Agriculture Faisalabad, Pakistan, having coordinates 31°26' N and 73°04' E. The data included minimum and maximum temperature, rainfall, wind speed, pan evaporation, sunshine hours and wind speed. The average maximum and minimum temperatures were 40°C and 4.5°C, wind speed from 0.1 m/sec to 0.8 m/sec and average rainfall was about 370 mm.

***Irrigation efficiencies*:** Water conveyance efficiency of existing irrigation system is not convincing. Overall efficiency of the canal irrigation system was estimated at 45%, showing huge losses in conveyance system (Bhatti *et al.*, 2009). According to Directorate of Land Reclamation (DLR, 2004) there exists 20% water loss in watercourses, 25% field losses and 16.8% losses in main canals for the use of departmental analysis in the Irrigation and Power Department, Punjab. This estimate also sums to an overall efficiency of about 40%. Therefore, an overall efficiency of 45% (from canal head to field level) was considered in this study.

***Methodology*:** In order to achieve desired objective, this study was divided into two main parts; i) Development of HRU's, and ii) Water demand of canal command area and its water gap analysis.

***Development of HRUs*:** Schematic diagram provided in Figure 1 illustrates HRU development process. Soil and Water Assessment Tool (SWAT) runs in ArcGIS environment and require data on land use, soil and topography to delineate HRUs that are unique for a particular land use, soil and slope. Land use at 250 m pixel resolution was developed using Moderate Resolution Imaging Spectro radiometer (MODIS) time series data available through official website of United States of Geological Survey (www.glovis.usgs.com). Topographic data at 90 m resolution was obtained from Shuttle Radar Topography Mission (SRTM) while FAO soil map was used to populate soil properties data. All dataset were re-sampled at 250 m to make it consistent. SWAT overlay three layers and provide a combination of these layers as a unique area representing similar land use, soil type and topography.

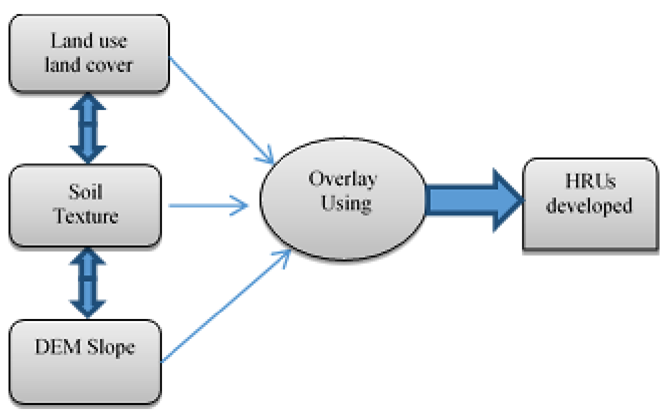

Figure 1. Schematic diagram of HRUs development.

***Crop water requirement calculations*:** The CROPWAT 8.0 calculates reference evapotranspiration (ET_o) based on Penman-Monteith equation, which assumes the reference crop evapotranspiration as that of a hypothetical crop with an assumed height of 0.12 m, having a surface resistance of 70 s/m and an albedo of 0.23, closely resembling the surface of green grass of uniform height, actively growing and adequately watered (Allen *et al.*, 1998). Crop water requirement (CWR) was calculated using equations given below:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

where,

ET_o = Reference evapotranspiration (mm day^{-1}),
R_n = Net radiation at the crop surface (MJ m^{-2} day^{-1}),
G = Soil heat flux density (MJ m^{-2} day^{-1}),
T = Mean daily air temperature at 2 m height (°C),
u_2 = Wind speed at 2 m height (m s^{-1}),
e_s = Saturation vapor pressure (kPa),
e_a = Actual vapor pressure (kPa),
$e_s - e_a$ = Saturation vapor pressure deficit (kPa),
Δ = Slope of saturated vapor pressure curve (kPa °C^{-1}),
γ = Psychrometric constant (kPa °C^{-1}).

Daily reference crop evapotranspiration (ETo) for the study area was collected from Pakistan Metrological Department (PMD) and then crop water requirement (CWR) was estimated using the appropriate crop coefficient K_c.

$$CWR\ (ET\ crop) = K_c \times ET_o \qquad (2)$$

The K_c provided by Food and Agriculture Organization (FAO) (Kassam and Smith, 2001) were used for estimating the monthly water requirement of crops. These estimations spanned over the period starting from emergence to crop maturity. Total irrigation requirement was estimated by adding up monthly water demand of all crops during whole season in each zone. The procedure is illustrated by flow chart diagram as shown in Figure 2.

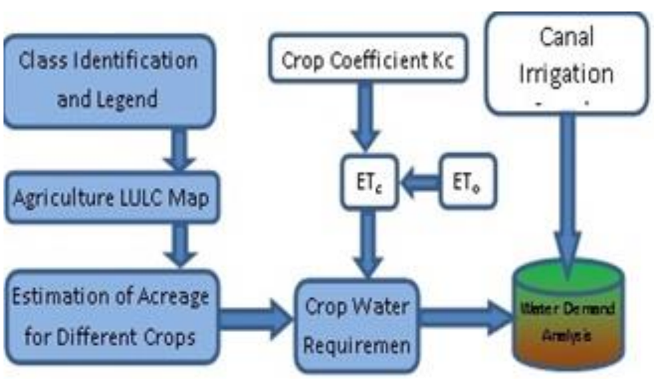

Figure 2. Flow chart diagram of crop water demand estimation.

RESULTS AND DISCUSSION

The Hydrological Response Units for Mungi and Killianwala distributaries, were developed and provided in Figure 3. There were 41 HRUs in Mungi distributary and 42 HRUs in Killianwala distributary. Each HRU has unique combination. The same color represented the same response at different places in canal command area. At the bottom side of Killanwala distributary cotton-wheat area is prominent while at upper side mixed cropping zone was found dominant. HRU 1 shows that fodder-cotton crop rotation on sandy loamy soil. In Mungi distributary, a mixed response was observed. Majority of HRUs showed fodder and wheat crops throughout the Mungi distributary area while sugarcane crop and wheat-maize cropping zone rarely found.

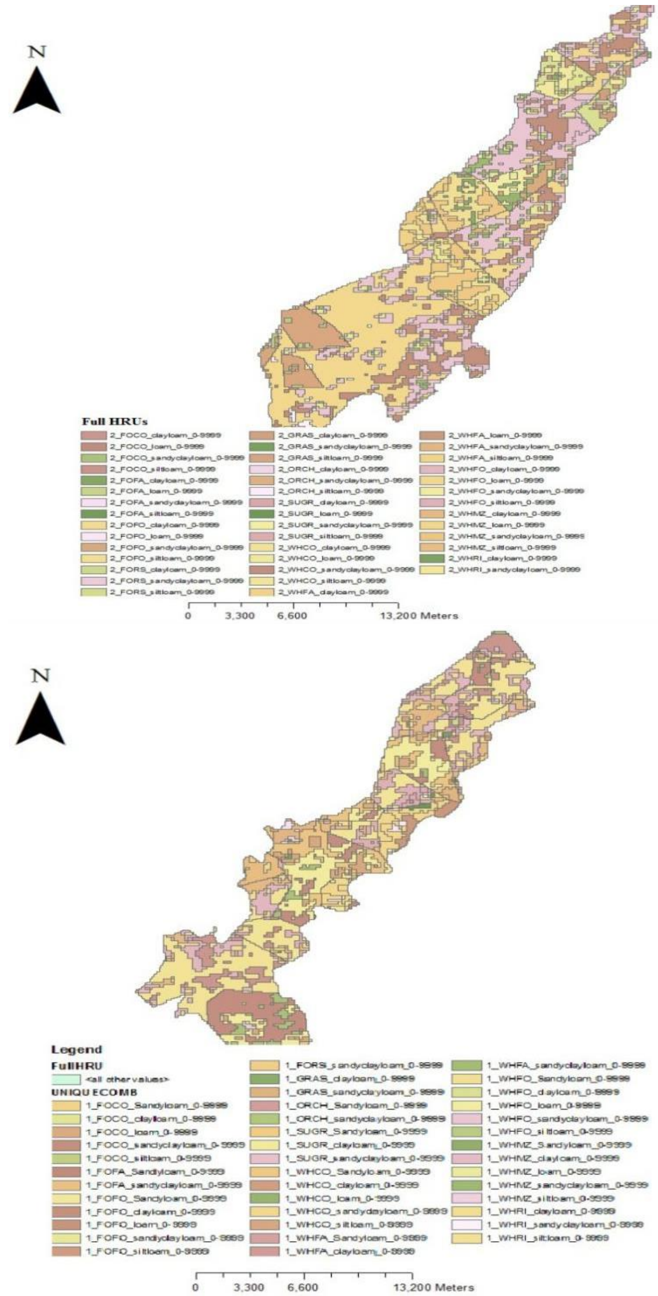

Figure 3. HRUs of Killianwala and Mungi distributary.

***Irrigation crop water requirement*:** Total irrigation water requirement (IWR) in HRUs of Killianwala and Mungi distributaries for the year 2011-12 was estimated as 365,478,414 m^3/year and 216,678,449 m^3/year, respectively. Crop water requirement of various major crops in the region were estimated using CROPWAT 8.0. The estimated CWR of major crops of the study area are shown in Figure 4. In *rabi* season, due to lower temperatures in December to February months, ET_o values are low as well as CWRs. But in *kharif*, due to higher temperature in June to September months, ET_o values are higher and resulting in higher CWR. Higher CWR was observed for sugarcane, rice, cotton, maize, and *kharif* fodders while lower CWR was recorded for wheat crop and *rabi* fodders. Crop water requirements varied with respect to cropping seasons and areas as it is depicted in the Indus Basin study, *rabi* and *kharif* crops water demand is ranged 240 mm to 462 mm and 341mm to 1004 mm, respectively (Ullah *et al*., 2001).

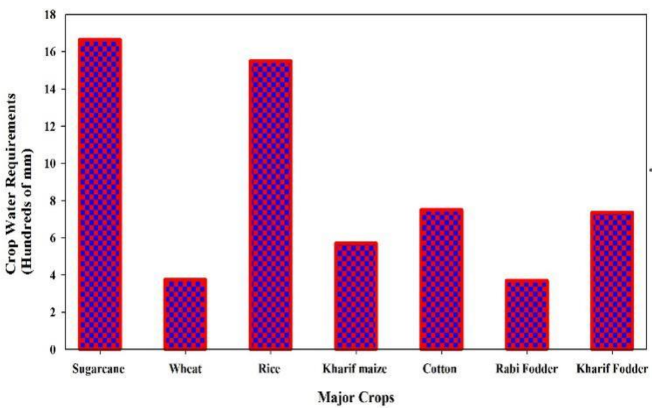

Figure 4. Crop water requirement (CWR) of various crops estimated through CROPWAT.

***Comparison of irrigation water supplies and demands*:** Total canal water supplies during the year 2011-12 delivered to Killianwala distributary and Mungi distributary were 1591.29 m^3/s and 1271.85 m^3/s respectively. The overall efficiency of the Pakistan canal irrigation system was determined as 45%, showing very high conveyance losses (Bhatti *et al.*, 2009).

After subtraction of conveyance losses, the net amount of available water for crops in command area of Killianwala distributary and Mungi distributary were 716.08 m^3/s and 600.65 m^3/s, respectively (Table 1).

Table 1. Available water supplies for Killianwala and Mungi distributaries.

Distributary	Annual Supplies (m^3/s)			
	2008-09	2009-10	2010-11	2011-12
Killianwala	714.26	699.78	811.36	716.08
Mungi	572.47	535.97	601.19	600.65
Total	1286.71	1235.76	1412.55	1316.73

From above data, it can be concluded that there is an average ratio of 1:4 between supply and demand. Demand is increasing with the time. The gap between supply and demand was found wider for tail users of each distributary.

Figure 5 indicates the supply and demand difference of Killianwala distributary is very narrow in November and December but at the end of January demand has been increased sharply.

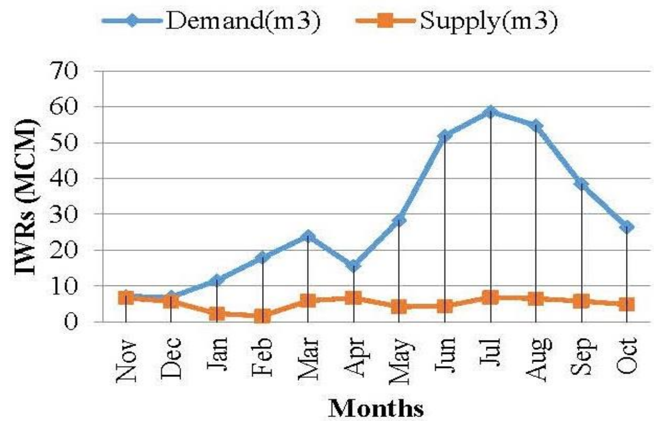

Figure 5. Comparison of water supplies and demands at Killianwala distributary.

The supply of both distributaries is little bit more than their demand at the start of *rabi* season to the end of December (Figure 5 & 6). Subsequently, the water supply curves touch abscissae, showing no water supply from the main canal in the month of February. This non-availability of water remains zero for the whole month. At this stage, only groundwater is utilized by the farmers to save their crops.

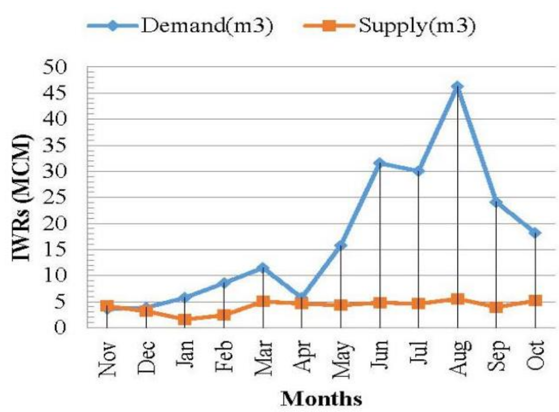

Figure 6. Comparison of water supply and demand at Mungi distributary.

The supply-demand gap was found widest in the months of June, July and August which prevails peak water demand in the command areas. If all canals would run at maximum supply level, then the total available water during the 2011-12 in both canals is 113,695,635 m^3 and estimated crop water requirement is 384,367,298 m^3.

This comparison of demand vs supply indicates that supply is always less than the demand during whole year. The supply-demand gap was found narrowest at the start of November to mid-January.

Comparison of supplied canal water vs. demand of *rabi* and *kharif* seasons showed that supply is relatively constant from November to the end of January and demand was increased at the start of February. Subsequently, the water demand increased sharply up to the end of August for Mungi distributary.

During field survey, it was also observed that crops of the tail users of the distributary were healthier than that of middle and head users. The possible reason behind it was that they applied tube well water to their crops, timely. Due to high cost of energy input the net benefit to the tail farmers was less than that of the farmers at the middle and head of the distributaries. If water is not properly or adequately delivered to the farmer at the tail, they will continue pumping groundwater which in turn result into declination of water table, soon. Eventually, the vast fertile land will turn into barren land.

***Conclusions*:** Unique combination of land use, soil and topography can be used to delineate Hydrological Response Units (HRUs). The analysis at the HRUs level reveals that there is a huge gap between water supplies and demand in both distributaries. The maximum water shortfall found in the month of August at Killianwala and Mungi distributary was 4.1 MCM/Year and 4.9 MCM/Year, respectively. HRUs are important for conversion of supply base into demand base system. If water is not adequately delivered to the tail farmers, they will continue pumping groundwater that will result into decline in water table.

REFERENCES

Arshad, M., N. Ahmad, M. Usman and A. Shabbir. 2009. Comparison of water losses between unlined and lined watercourse in Indus Basin of Pakistan. Pak. J. Agri. Sci. 46:280-284.

Bates, B., Z. Kundzewicz, and S. Wu. 2008. Climate change and water. Inter-governmental panel on climate change, secretariat, Geneva, Switzerland; 6:1-200.

Bhatti, A.M., P. Suttinon and S. Nasu. 2009. Agriculture water demand management in Pakistan: A review and perspective. J. Soc. Social Manage. Syst. 172:1-7.

Bhutta, M.A. and E.J.V. Velde. 1992. Equity of water distribution along secondary canal in Punjab, Pakistan. J. Irrig. Drain. Syst. 6:161-171.

Cheema, M.J.M. and W.G.M. Bastiaanssen. 2010. Land use and land cover classification in the irrigated Indus Basin using growth phenology information from satellite data to support water management analysis. J. Agric. Water Manage. 97:1541–1552.

DLR. 2004. Water allowance of all canals of upper Indus Basin Irrigation System: The Current Status. Directorate of Land Reclamation, Punjab Irrigation and Power Department, Lahore, Pakistan.

Hafeez, M. and S. Khan. 2005. Remote sensing application for estimation of irrigation water consumption in Liuyuankou Irrigation System in China. Proc. 16th Congress of the Modelling and Simulation Society of Australia and New Zealand, Melbourne, Australia. Workshop, Dec. 12-15, 2005.

Jehangir, W.A., A.S. Qureshi and N. Ali. 2002. Conjunctive water management in the Rechna Doab: An overview of resources and issues. International Water Management Institute, Colombo, Sri Lanka.

Kassam, A. and M. Smith. 2001. FAO Methodologies on crop water use and crop water productivity. In: Expert Meeting on Crop Water Productivity, Rome, Italy. Dec. 3-5, 2001.

Shabbir, A., M. Arshad, A. Bakhsh, M. Usman, A. Shakoor, I. Ahmad and A. Ahmad. 2012. Apparent and real water productivity for cotton-wheat zone of Punjab, Pakistan. Pak. J. Agri. Sci. 49:357-363.

Tariq, J.A. and M.J. Kakar. 2010. Effect of variability of discharges on equity of water distribution among outlets. Sarhad J. Agric. 26:51-59.

Ullah, M.K., Z. Habib and S. Muhammad. 2001. Spatial distribution of reference and potential evapotranspiration across the Indus Basin Irrigation Systems. International Water Management Institute, Lahore, Pakistan.

Water and Power Development Authority. 2011. Hydro Potential in Pakistan. Pakistan. Available online at www.wapda.gov.pk