

# ONLINE IRRIGATION PERFORMANCE ASSESSMENT TOOL- A CASE STUDY IN HAKRA 4R IRRIGATION CANAL PAKISTAN

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**ABSTRACT:** Nowadays, the trend is to use internet based automated Geographic Information System (GIS) applications (or Web based GIS applications) to overcome issues related with GIS and Remote Sensing (RS) applications. A web based GIS application is hosted in a powerful server with its associated GIS components and the GIS operations are catered as per the end user requirements. The GIS components are preprogramed to process data within the server and return the output to the user over the internet (using a web browser). Thus, the main objectives were to setup a web processing environment using robust open source GIS software packages and implement web based solution for irrigation performance assessment. The study area was the irrigation system of Hakra Branch Canal (HBC) of Pakistan. MODIS products were taken as the key inputs to the system. The system used web processing services, GRASS modules, GDAL and numpy python packages at the server end to produce the remote sensing outputs at the server end. Generation of ET and evaporative fraction (EF) maps and returning its associated statistical outputs is the functionality of the tool. This tool provides performance indicators Adequacy, Equity and Reliability in the form of statistical figures and graphs. Adequacy refers to the adequate water supply for an irrigated land and the system does produce the indicator figure by use of EF map. Equity refers to equal water supply for the irrigated land and the system generates the indicator by coefficient variant of ET actual map. Reliability is the temporal behavior of Adequacy and it is provided in a graph output by the system. Therefore, this study demonstrates the application of surface energy balance techniques to map spatial and temporal variation in actual evapotranspiration (ET<sub>a</sub>) using freely available MODIS images and routine climatic data.

## 1.1 INTRODUCTION

By the year 2025, 83% of the expected global population of 8.5 billion is expected to live in developing countries. The world's food production depends on the availability of water, a precious but finite resource (UNCED, 2002). The agricultural sector is one of the biggest consumer of water resources, accounting in Asia and the Pacific region it is as high as 90% (Barker *et al.*, 2005). The use of this irrigation water plays a major role in increasing land productivity. Globally, about 40% of agricultural outputs and 60% of grain production is produced from irrigated areas which together make up only 17% of all arable land (Seckler *et al.*, 1998). However, population growth & the effects of cyclic droughts on irrigated agriculture have put pressure on the available water resources. Under this perspective, effective planning & management can only be obtained on the basis of reliable information irrigation performance. It is necessary to employ modern methods such as Remote Sensing (RS) & GIS for irrigation water management.

Performance assessment is considered the most critical element for improving irrigation management. The evaluation of irrigation systems has undergone major development during the last 3 decades. Those are moving from a focus on classical irrigation efficiencies to performance indicators and more recently, to frameworks of water accounting and productivity (Bos *et al.*, 1974; Molden, 1997; Clemmens *et al.*, 1997). Irrigation Performance Indicators range from water distribution to agricultural, economic, social and environmental aspects. In the present study, Equity, Adequacy and Reliability of water supplies to cropped area, are considered as Irrigation Performance Indicators. Equity is the equal or proportional distribution of water among farmers. Adequacy is defined as the average seasonal evaporative fraction. Reliability defined as the temporal variability that is temporal coefficient of variation of evaporative fraction in a season. Evaporative fraction values of 0.75 or higher indicate no stress (Bastiaanssen *et al.*, 1999), and below 0.75 reflect increases in moisture shortage to meet crop water requirements as a result of inadequate water supplies. Similarly, the lower values of coefficient of variation represent the more reliable water supplies throughout the

cropping season. The term water productivity is defined as the physical mass of production or the economic value of production measured against gross inflows, net inflow, depleted water, process depleted water, or available water (Molden *et al.*, 1999).

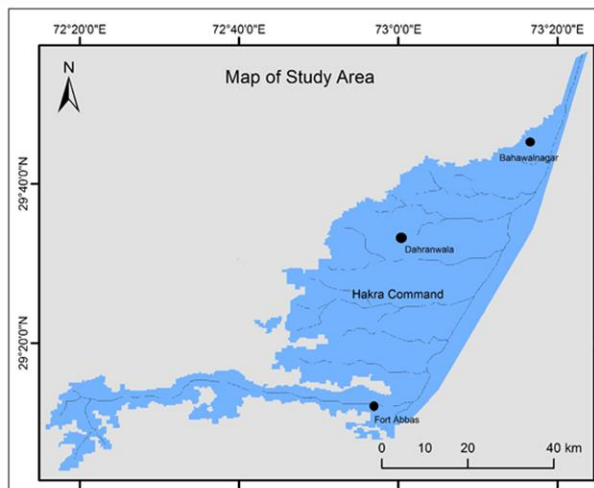
RS was identified as a tool for assessing performance of an irrigation system couple of decades ago. Moran *et al.* (1994) described the results of a farm irrigation management study in Arizona where the maximum possible cloud-free SPOT and Landsat images. Alfalfa and cotton were continuously monitored in terms of Vegetation Index (SAVI) and surface temperature to deduce the Water Deficit Index (WDI) for adequacy evaluations (Moran *et al.*, 1994). Adequacy and reliability of water supplies to cropped area can be assessed using the evaporative fraction maps as they 13 directly reveal the crop supply conditions (Alexandridis *et al.*, 1999).

Development of an online tool using RS is viewed as an efficient tool for irrigation water management. Availability of such a tool can provide performance indicator values on the Area of Interest (AOI) of the user within a short period. Use of free satellite data and open source geo processing tools with open source software development environments can lead to a cost effective solution. Implementation of a client server raster processing architecture can save cost and time which is required for data processing, analysis and presenting. When implementing such a geo spatial solution, use of a Web Processing Service (WPS) and a robust GIS/RS processing tool over the World Wide Web (WWW) are required.

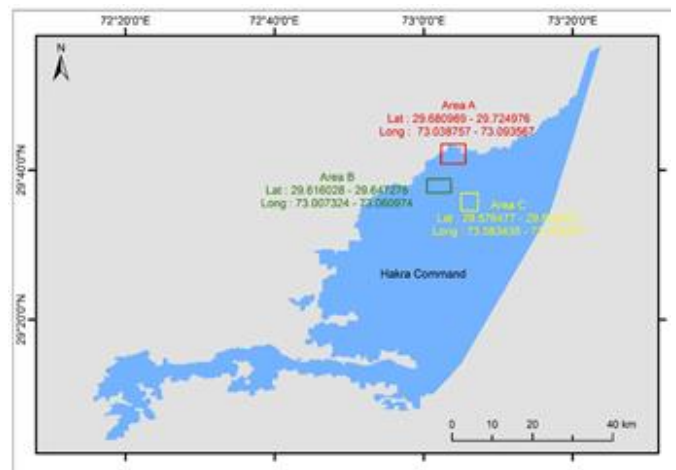
The main objectives of the study were to develop an online Irrigation Performance Assessment tool, to assess the irrigation performance of Hakra Branch Canal (HBC) of Pakistan, while checking the consistency of identified parameters three parameters Equity, Adequacy and Reliability.

## 1.2 Study Area

The study area is irrigation system of HBC of Pakistan. It is located on the Eastern border of Pakistan. The canal is approximately 74 km of this branch Canal in length and trifurcate into the HBC. HBC lays between longitude 72.241 and 73.412 East and latitude 29.952 and 29.061 North (Figure 1). The gross command area of HBC is 0.67 million acres out of which cultivable command area is 0.54 million acres. For the ease of analysis labeled the area selections as Area A, Area B and Area C in Hakra Branch Canal Pakistan (Figure 2).



**Figure 1:** Map of Study Area (Hakra Branch Canal of Pakistan)



**Figure 2:** Area A, Area B, Area C in HBC

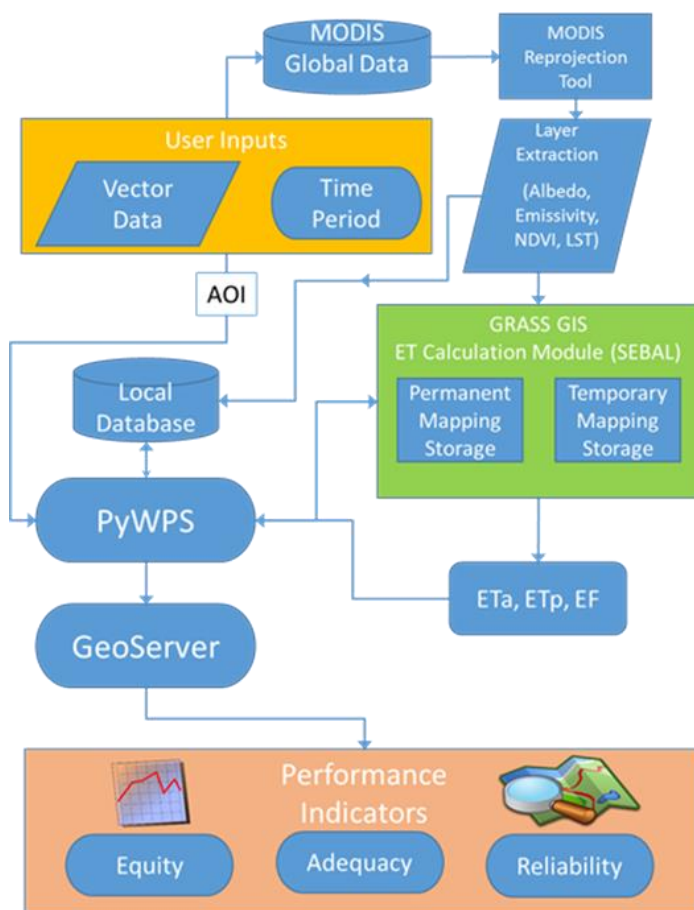
## 2.0 METHODOLOGY

Figure 3 gives the methodology of the study. As data inputs, the tool uses the three products from MODIS such as MOD13Q1, MOD11A2 and MCD43B3. MODIS datasets are generally compressed with .hdf format which is a unique file format for MODIS. There are several raster bands compressed within a single dataset of MODIS (or an .hdf file). An API was developed to read and extract the raster bands in geotiff format from the MODIS .hdf

dataset. The API communicates with the MODIS Resampling Tool to set necessary projection parameters, file formats, raster bands and other required outputs. The API then extracts the bands into geotiff files (images) and applies the naming convention for the extracted images to be used in GRASS GIS.

GRASS GIS 7 is used for raster data processing at the server end. GRASS engine has been connected externally by separate APIs to run GRASS commands. An API was developed using Python to upload previously extracted geotiff files in to GRASS server. The API uploads NDVI, Emissivity, Albedo and Land Surface Temperature maps to the GRASS server. In the meantime the API updates the local PostgreSQL database about uploaded files to the GRASS Server. In this tool the SEBAL model has been implemented with GRASS GIS 7 to calculate Evapotranspiration maps. In the process of generating the evapotranspiration maps several other input maps have to be generated and include net radiation map, sensible heat flux map, soil heat flux map and evaporative fraction map.

The Web Processing Service (WPS) used in this tool is a Python implementation of OGC's WPS 1.0.0 protocol on the server side. A special protocol is required to publish the geo referenced maps/images over the internet. It is called Web Map Service (WMS). The Geo Server is used to publish the raster maps. The program creates required coverage stores on the fly on Geo Server to publish the raster maps. Once the geotiff is created by the PyWPS process, it is uploaded to the Geo Server and a WMS url is returned to the user.



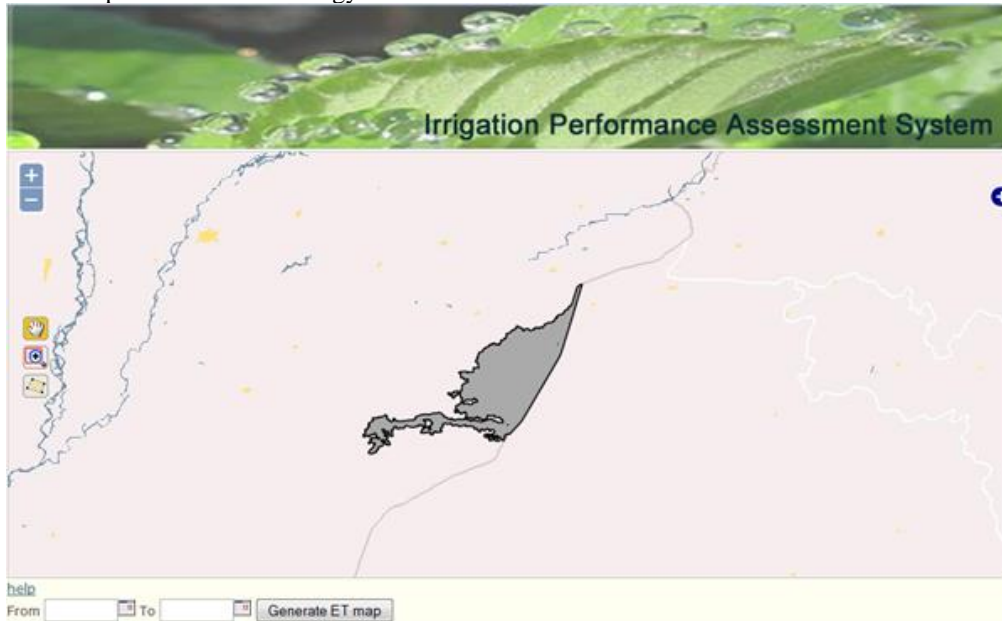
**Figure 3** Overall Computational Process

### 3. DATA PROCESSING AND RESULTS INTERPRETATION

#### 3.1 Inputs and Outputs of Online Tool for IPA

The resulted interface of online tool is to be manipulated in order to input data such as Area of Interest (by drawing a rectangle on the map), start date, and end dated for data processing and confirmation to calculate data (by a click of an HTML button) by users.

On the home page an OpenLayer map has been provided with the base map in the background. The study area map is overlaid for the user to point on the Area of Interest. Once area is selected to start processing data at the server end user should click on “Generate ET map” button (Figure 4). Then the whole process starts and continues at the server end as explained in methodology.



**Figure 4** User Interface of Inputs

**3.2. Raster Inputs** Once the user provided the Area of Interest along with the date range, the system picks the necessary raster inputs which have already uploaded to the GRASS database and clip them in order to process according to user selected area. GRASS ET Calculation Model requires following products as inputs and the system generates those products prior to invoke GRASS ET model.

**3.2.1. Albedo** Albedo map is directly taken from the MODIS product MCD43B3 and uploaded to GRASS database. Figure 5 shows three albedo maps used for this case study with relevant to Area A, Area B and Area C.

**3.2.2. DEM** The area is clipped as of the user’s interest of the area. Figure 6 shows three DEM input maps generated by the tool to be used for this case study with relevant to Area A, Area B and Area C.

**3.2.3. Emissivity** Emissivity map is extracted from the MODIS product MOD11A2 and uploaded to GRASS database. Figure 7 shows three emissivity maps clipped by the tool for this case study with relevant to Area A, Area B and Area C.

**3.2.4. NDVI** NDVI map is extracted from the MODIS product MOD11A2 and uploaded to GRASS database. Figure 8 shows three NDVI maps clipped by the tool this case study with relevant to Area A, Area B and Area C.

**3.2.5. Land Surface Temperature** Land Surface Temperature map is extracted from the MODIS product MOD11A2 and uploaded to GRASS database. Figure 9 shows three land surface temperature maps clipped by the tool for this case study with relevant to Area A, Area B and Area C.

**3.3. Raster Outputs** Though the ultimate goal of the system is to produce ET map and its indicators, the system has to generate number of intermediate maps in order to set inputs for GRASS ET model. Major data processing steps (in the form of raster maps) and their associated intermediate raster outputs are as discussed below.

**3.3.1. Net Radiation (Rn)** Calculation of surface radiation is done at this stage. The Rn function was developed using GDAL and numpy python libraries. It takes albedo, emissivity and temperature maps as the inputs. Figure 10 shows three net radiation maps generated by the system for Area A, Area B and Area C.

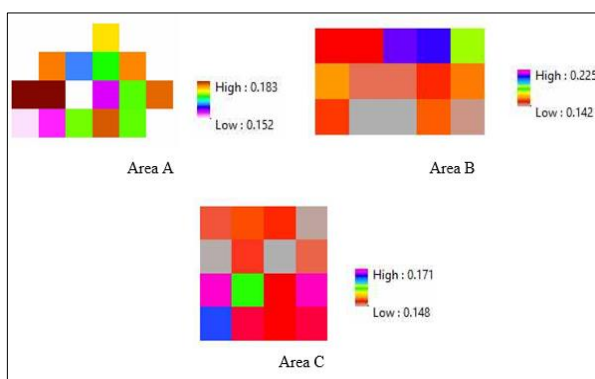
**3.3.2. Sensible Heat Flux** GRASS module i.eb.h\_sebal01 is used for generating the soil heat flux map. This module calculates the sensible heat flux map for both Net Radiation and Sensible Heat flux maps. Figure 11 shows three

sensible heat flux maps generated by the system for Area A, Area B and Area C.

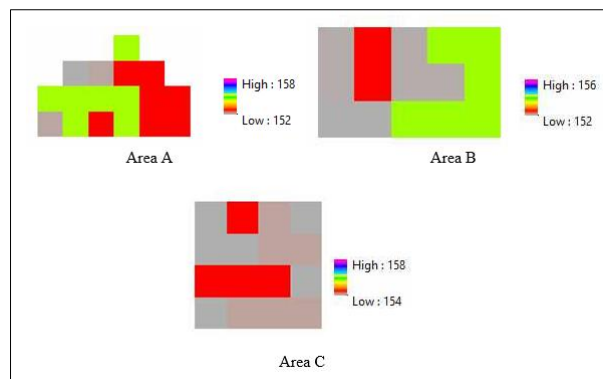
**3.3.3. Latent Heat Flux** GRASS module `i.eb.h_sebal01` is used for generating the latent heat flux map. Figure 12 shows three latent heat flux maps generated by the system for Area A, Area B and Area C.

**3.3.4. Evaporative Fraction** Once the above maps are generated, the inputs for GRASS ET modules are ready to use. GRASS module `i.eb.evapfr` is used to generate the evaporative fraction map and it takes net radiation, soil heat flux and sensible heat flux maps as inputs. Figure 13 shows three evaporative fraction maps generated by the system for Area A, Area B and Area C.

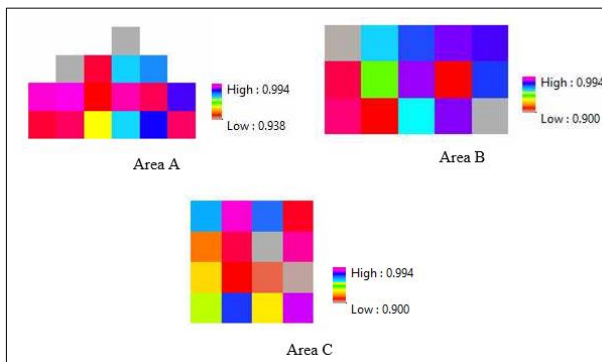
**3.3.5. Evapotranspiration** With given Evaporative Fraction map, Net Radiation, and land surface temperature maps GRASS module `i.eb.eta` is used to generate the actual Evapotranspiration map. Figure 14 shows three evapotranspiration maps generated by the system for Area A, Area B and Area C.



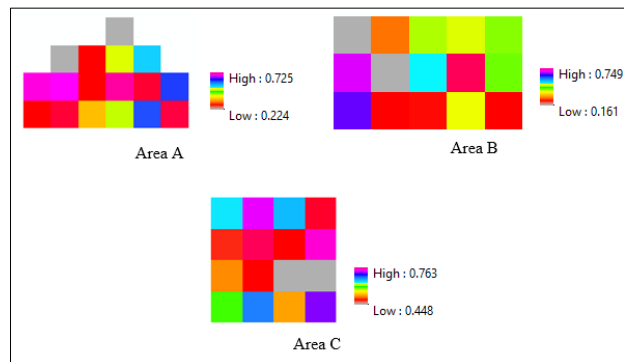
**Figure 5** Input Albedo Map for Area A, B, C



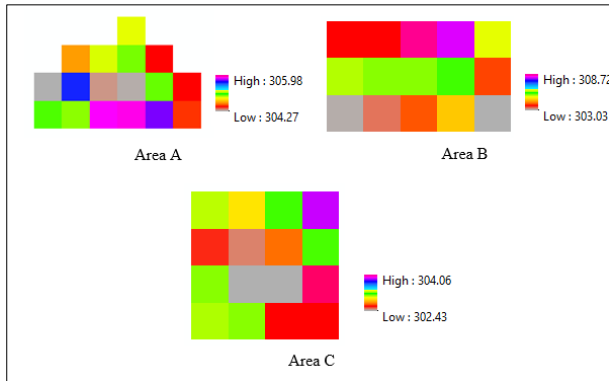
**Figure 6** Input DEM Map for Area A, B, C



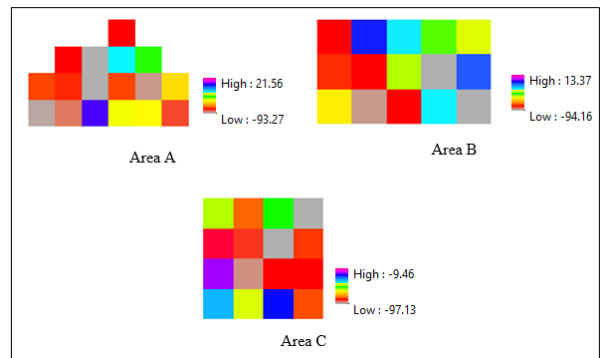
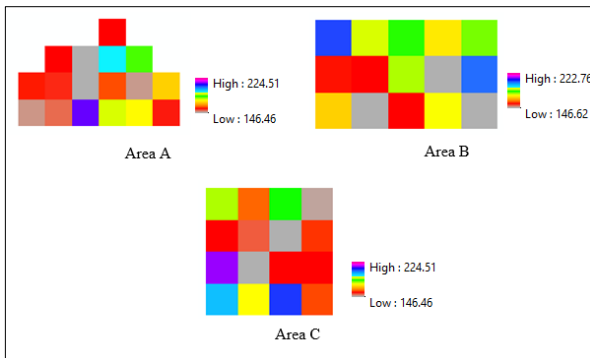
**Figure 7** Input Emissivity Map for Area A, B, C



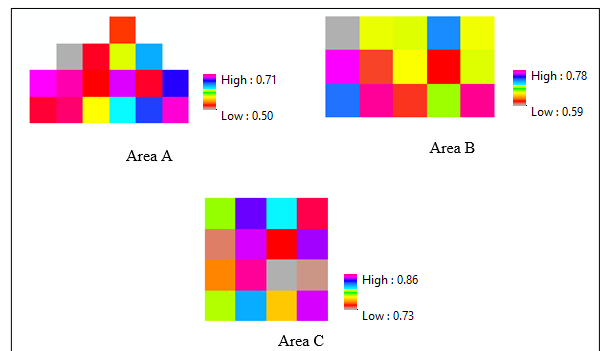
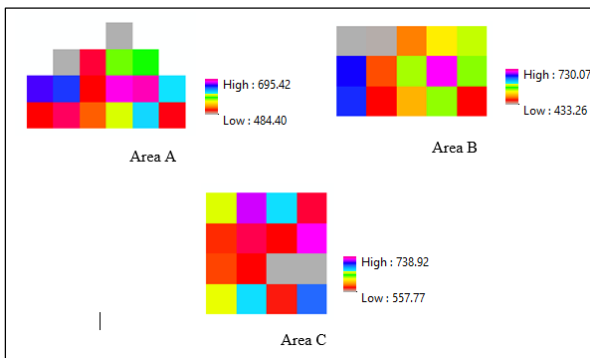
**Figure 8** Input NDVI Map for Area A, B, C



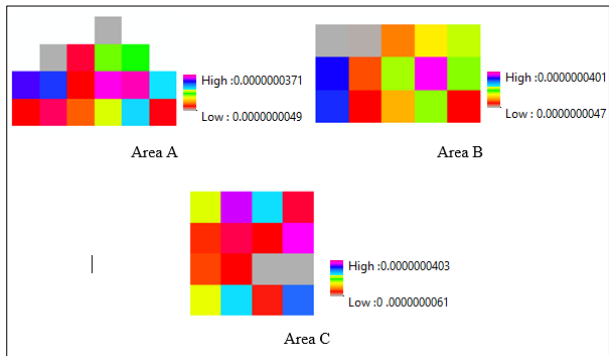
**Figure 9** Input Land Surface Temperature Map for Area A, B, and C



**Figure 10** Output Soil Heat Flux Map for Area A,B,C **Figure 11** Outputs Sensible Heat Flux Map for Area A, B,C



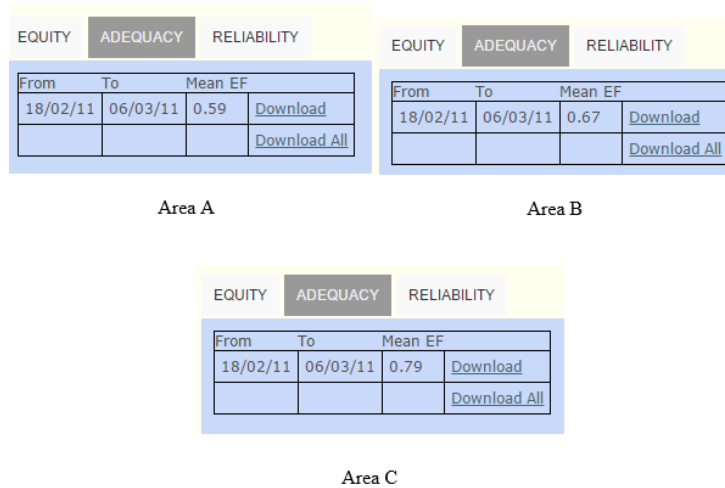
**Figure 12** Output Latent Heat Flux Map for Area A, Area B and Area C **Figure 13** Outputs Evaporative Fraction Map for Area A, Area B and Area C



**Figure 14** Output Evapotranspiration Map for Area A, Area B and Area C

### 3.4. Indicator Outputs

Once processing of raster maps are finished at the server's end, result is sent back to the client end. The tool provides resulted outputs to the user through the user interface in the form of a raster web map service, ET and EF statistical outputs Adequacy, Equity and Reliability. The created raster maps are displayed on the Open Layer user interface through the GeoServer WMS. The outputs for the equity, adequacy and reliability are displayed under the indicators tab group. At the end of the processing of data, the statistical figures for the above mentioned indicators are displayed in the form of a table by the tools user interface under each relevant result section. Figure 15 shows indicator outputs generated by the tool for Area A, Area B and Area C. Similar ways, Equity and Reliability indicator outputs are shown in the tool.



**Figure 15** Indicator Outputs (Adequacy) Generated by the Tool for Area A, Area B and Area C

It is possible to assess Adequacy, Equity and Reliability indicators with the outputs generated by the tool for an identified irrigation system ( eg:- Area A, Area B, Area C as discussed ). In the case study Area A and Area B were having less adequate water availability as the adequacy indicator values were less than 0.75. Adequacy figure for Area C was interpreted with adequate water availability as adequacy indicator value was greater than 0.75. With the Equity values returned for Area A and Area B, it was indicating that Area A and Area B are not having a proper distribution of water as the indicator value was much higher. Area C was having an Equity figure less than 1 which indicated a proper distribution within Area C.

### 4.0 CONCLUSIONS

This paper demonstrates, freely available MODIS images derived raster maps (such as actual evapotranspiration and evaporative fraction) can be merged with vector maps of the irrigation water delivery systems to understand the real time performance under actual field conditions. In this study, indicators representing equity, adequacy and reliability are used to evaluate the performance of irrigated agriculture in the Hakra Branch Canal (HBC), Pakistan. The tool can be used to assess Irrigation Performance using indicator (Equity, Adequacy, Reliability) values for a specified area and for a given time period. In the case study area A, B, and C was considered. For the geo application developers who are interested in implementing Open Source Web Processing Services for their projects, are able to set similar environment and implement for different online products.

### 5.0 RECOMMENDATIONS

This tool can be expanded both in terms of spatial and temporal coverage i.e. to cover the whole globe spatially and temporally depending on the availability of the global data. The strength of the system lies in its being an online system with simple user interface and making user capable of acquiring information about its irrigation system without the expertise required to understand the spatial concepts, models and knowledge to run complicated algorithms to calculate ET.

## 6.0 REFERENCES

- Barker, R. and Molle, F. (2005). Evolution of irrigation in South and Southeast Asia, Comprehensive Assessment Research Report, International Water Management Institute (IWMI), Colombo, Sri Lanka.
- Bastiaanssen, W. G. M. (2000). SEBAL-based sensible and latent heat fluxes in the irrigated Gediz Basin, Turkey. International Water Management Institute (IWMI), Colombo, Sri Lanka.
- Bos, M. G. and Nugteren, J. (1974). On irrigation efficiencies, International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands: 138 pp.
- Clemmens, A. J., and Burt, C. M. (1997). Accuracy of irrigation efficiency estimates; *Journal of Irrigation and Drainage Engineering*, vol. 123(6), 443-453.
- Molden, D., (1997). Accounting for water use and productivity. SWIM paper 1. International Irrigation Management Institute (IIMI), Colombo, Sri Lanka.
- Moran, M. S. (1994). Irrigation management in Arizona using satellites and air planes, *Irrig.Science*.
- Seckler, David; David Molden; and Randolph Barker. 1998. Water scarcity in the twenty-first century. IWMI Water Brief 1. Colombo, Sri Lanka: International Water Management Institute.
- UNCED (U.N. Conference on Environment and Development), Agenda 21, at 76, U.N. Doc. A/CONF. 151/4 U.N. Sales No. E.92.1.16 (2002).