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Blockwise assessment of crop evapotranspiration in central Punjab, India

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ABSTRACT

Punjab, the major riparian State, has a limited share in its three perennial rivers (Sutlej, Ravi and Beas). A systematic planning of groundwater exploitation using modern technologies needs to be adopted for the proper utilization and management of groundwater resource. The present study was aimed to estimate the blockwise crop evapotranspiration (ET_c) during *kharif* and *rabi* season in Central Punjab and to develop a GIS based maps of crop evapotranspiration. The results revealed that the blocks namely Makhu and Zira of Ferozepur district had the maximum (747 mm) crop water demand whereas block Fatehgarh Churian of Gurdaspur district had the least (445 mm) crop water demand. The outcome of the study revealed that crop water demand varies from 450 mm to 750 mm in *kharif* and *rabi* season in Central Punjab. The ET_c maps derived in the study were useful in determining areas with highest water demands.

Key words: Crop evapotranspiration, GIS, Papadakis equation.

INTRODUTION

Punjab having geographical area of about 50,362 km^2 (1.54 percent of the country's geographical area) with about 82 per cent of the state's geographical area is cultivated with cropping intensity of more than 189 per cent during 2013-14 (Anonymous, 2015). The agriculture in the state is, therefore, dependent upon high requirement of water. Punjab, the major riparian State, has a limited share in its three perennial rivers (Sutlej, Ravi and Beas). The annual water available in the state is 3.13 MHM against the annual demand of 4.4 MHM. Thus, there is deficit of 1.27 MHM of water which is being met by overexploitation of underground water resources. The number of tubewells has increased from 1.92 lakh to 14.04 lakh during the period 1970 to 2013-14. The Central zone, which comprises districts namely Amritsar, Kapurthala, Jalandhar, Ludhiana, Fatehgarh, Sangrur and Patiala, is covering 47 percent of the total geographical area of the state (Vashisht, 2008). This zone is the most developed area of the State. The lands are properly levelled and undergroundwaterisavailable for irrigation.The over exploitation of sub-soil water is causing ground water depletion in this zone at an alarming rate. The problem of overexploitation of groundwater resources is most severe in Central Punjab, usually called sweet water zone and dominated by rice crop in the *kharif* season. While the average annual fall in groundwater table in the Central Punjab was about 17 cm during the 1980s and about 25 cm during the 1990s, it was alarmingly high at 91 cm per annum during 2000 – 2005 (Singh, 2011).

Evapotranspiration (ET) is a major component of the hydrologic cycle, its quantity is of major concern to water resource planners around the world. Estimates of evapotranspiration provide an outlook of soil water balance in association with the amount of precipitation. Such estimates are of immense importance for calculation of water demand of the field crops and irrigation scheduling (Rasul, 1992). It also determines the nature of agro-climate a region, agro-climatic potential of that region and suitability of crops or varieties, which can be grown successfully with the best economic returns (Rasul and Farooqi, 1993).

Since the Central zone of Punjab is facing problem of declining water table, so there is need to manage the available surface and ground water resources optimally to sustain agriculture. A systematic planning of groundwater exploitation using modern technologies needs to be adopted for the proper utilization and management of groundwater resource. Keeping in view, the study was planned to evaluate the crop evapotranspiration (ETc) of different blocks and to map the ET_c using GIS in Central Punjab.

MATERIALS AND METHODS

Description of the Study area: The study was conducted in the Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana. Punjab is divided in three zones namely North-east, Central and South-west Punjab. Central Punjab covers complete districts of Fatehgarh Sahib, Jalandhar, Kapurthala, Ludhiana, Patiala most parts of Amritsar, Gurdaspur, Hoshiarpur, Moga, Sangrur, Tarn Taran and few blocks of Ferozepur and Nawan Shahar. It covers approximately 47% geographical area of Punjab. The soil of central Punjab ranges from sandy loam to clayey with pH value ranges from 7.8 to 8.5 making alkalinity and salinity

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problematic for this place. The alluvial soil of this zone can be widely described as arid and brown soil or tropical arid brown soil.

Climate is characterized by extreme hot and extreme cold conditions. Annual temperatures ranges from 1 °C to 46 °C (min/max), but can reach 49 °C in summer and 0 °C in winter. They are the summer months that spans from mid April to June. The rainy season is from the months of early July to end of September. The winter season is experienced during the months of early December to the end of February. The average monthly minimum and maximum temperature and average monthly rainfall during *kharif* and *rabi* season is presented in Fig.1 and Fig.2.

Calculation of reference evapotranspiration (ET_o): The actual evapotranspiration (ET_a) is the quantity of water which is transferred as water vapour to the atmosphere from an evaporating surface under real conditions (e.g. water availability, vegetation type, physiological mechanisms, climate), whereas ET_o represents the atmospheric evaporative demand of a reference surface (generally a grass crop having specific characteristics), and it is assumed that water supply from the land is unlimited (Allen *et al.*, 1998). ET_a will be less than or equal to ET_o, but never greater.

Although there are several methods for determination of ET_o like Thornthwaite equation (Thornthwaite, 1948), Blaney-Criddle equation (Blaney and Criddle, 1950), Penman-Monteith (Allen *et al*., 1998) equation. The method used in this study was the Papadakis equation (Papadakis, 1965) as this method requires minimum meteorological data for estimation of ET_o. Also the Potential Evapotranspiration predicted by Papadakis is more reliable and useable than the Thornthwaite equation which also requires minimum meteorological data (Kingra *et al*., 2002; Singh *et al.,* 2003). The method relies only on measurement of maximum and minimum air temperatures which is relatively cost-effective option and it out performs some other methods that require measurement of large number of variables. Also, the simplicity of this method recommended its use in arid and semi arid regions (Donald *et al.,* 2007). Papadakis used saturation vapor pressure corresponding to monthly temperatures to estimate ETo (mm month^{-1}). The following equations were used:

$$ETo = 0.5625*(e_{max} - e_{min-2})*(10/30)$$

$$e_{max} = (33.8639*(0.00738*T_{max}+0.8072)^8)-(0.000019*(1.8*T_{max}+48)+0.001316)$$

$$e_{min-2} = (33.8639*(0.00738*(T_{min}-2)+0.8072)^8)-(0.000019*(1.8*(T_{min}-2)+48)+0.001316)$$

where,

T_{max} = average maximum temperature

T_{min} = average minimum temperature

e_{max} = saturation water pressure corresponding to average maximum temperature

e_{min-2} = saturation water pressure corresponding to dew point temperature.

Papadakis concluded that dew point temperature is roughly equal to daily minimum temperature minus 2 degree.

ETo = reference evapotranspiration (Papadakis, 1965)

Calculation of Crop Evapotranspiration (ET_c): For calculating crop evapotranspiration, data of total area under major *kharif* and *rabi* crops (2007-2013) was collected from Statistical Department of Agriculture, Punjab. During *kharif* season, the main crops in study area were paddy, maize, cotton, oilseeds and sugarcane, whereas during *rabi* season, wheat and oilseeds were the main crops. The total ET_c for particular season was estimated using area under each crop, ET_o, Crop coefficient (K_c) of that crop and growing period. Total ET_c in ha-m = Area in ha*ET_o in m *K_c*Growing Period Growth stage wise crop coefficients and crop growth stages (days) for different crops given by Kaushal (1988) were used for the study (Table 1 and 2).

Table 1: Crop coefficients (K_c) and Number of days in each month for *kharif* crop

	Paddy		Cotton		Maize		Oilseeds		Sugarcane	
	(K_c)	Days in each month	(K_c)	Days in each month	(K_c)	Days in each month	(K_c)	Days in each month	(K_c)	Days in each month
Jan	0	0	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0	0.52	0
Mar	0	0	0	0	0	0	0	0	0.85	0
Apr	0	0	0.15	19	0	0	0	0	0.97	17
May	0	0	0.31	31	0	0	0	0	1.05	31
Jun	1.01	15	0.76	30	0.23	6	0.23	22	1.05	30
Jul	1.03	31	1.03	31	0.48	31	0.48	31	1.05	31
Aug	1.08	31	1.04	31	0.96	31	0.96	31	1.05	31
Sep	1.05	30	0.9	30	1.01	30	0.99	30	1.05	30
Oct	1	15	0.7	15	0.6	15	0.7	15	1.05	15
Nov	0	0	0	0	0	0	0	0	0.92	0
Dec	0	0	0	0	0	0	0	0	0	0

Source: Kaushal (1988)

Table 2: Crop coefficients (K_c) and number of days in each month for *rabi* crops

	Wheat		Oilseeds	
	Crop Coefficient (K_c)	Days in each month	Crop Coefficient (K_c)	Days in each month
January	1.11	31	0.99	31
February	1.15	28	0.97	28
March	0.82	31	0.85	31
April	0.25	14	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0.4	0	0.4	6
November	0.51	22	0.52	30
December	0.85	31	0.85	31

Source: Kaushal (1988)

GIS Mapping: GIS has capabilities to integrate database, statistics, remote sensing, maps with advance graphics for visualization and analysis. With its powerful capacity for management and analysis of spatial data, GIS becomes an important tool in irrigation management (Lin *et al*, 2004). In GIS mapping of South-west Punjab ArcGIS 9.3 software was used and classified ET maps were created. The area under different categories of ETc was computed using zonal tool of ArcGIS 9.3. From GIS Mapping, ET_c can be clearly visualised.

RESULTS AND DISCUSSION

The required data was obtained from various agencies for the determination of ET_c of Central Punjab and it was determined by adopting the methodology described.

The average annual ET_c for the study period (2007-2013) was as shown in Fig.3. The year 2009-10 experiences maximum average ET_c of 24,26,700 ha-m in Central Punjab. The highest ET_c during 2009-10 might be attributed to the highest maximum and minimum temperature during *kharif* and *rabi* season. Out of total ET_c, 13,90,858 ha-m (57.3%) was during *kharif* season and 10,35,841 ha-m (42.7%) was during *rabi* season. While the minimum average annual ET_c was experienced during the year 2011-12 (20,81,338 ha-m). This lowest ET_c during 2011-12 might be attributed to the low maximum and minimum temperature. In terms of depth (mm), maximum average annual ET_c was 747 mm in blocks of Ferozepur district during *kharif* season and 547 mm in Amloh block of Fatehgarh Sahib district during *rabi* season (as shown in Table 3).

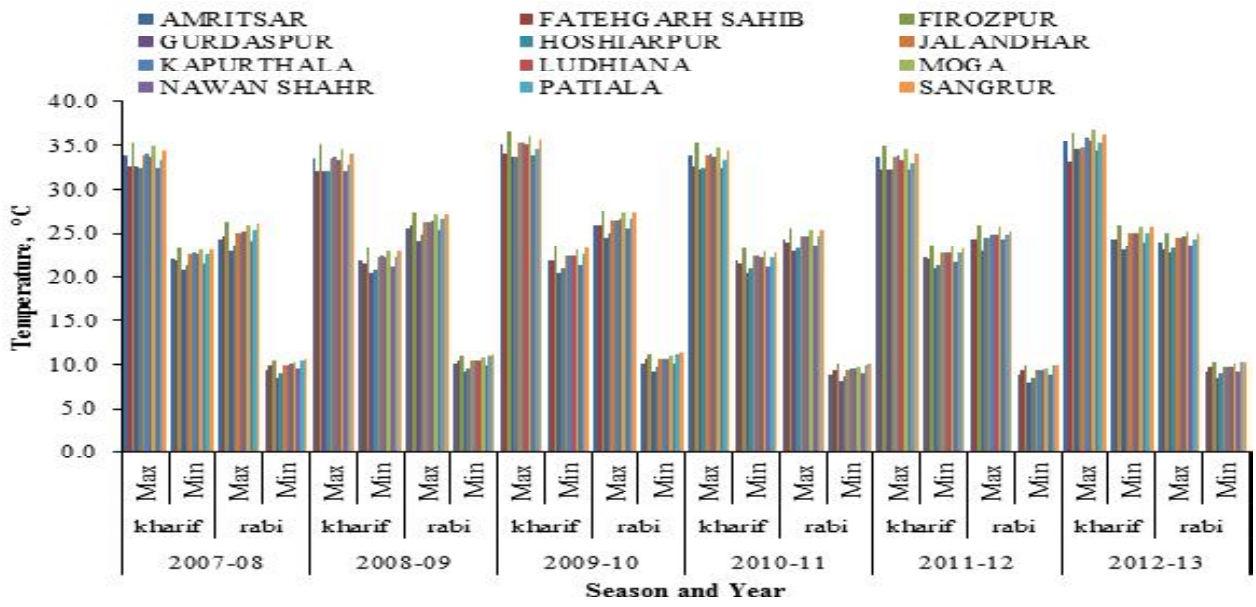

Fig 1: Average monthly temperature of districts of central Punjab

Table 3: Average annual ET_c (in mm) for different blocks in *kharif* and *rabi* season

Block Name	Average Evapotranspiration (mm)	
	Amritsar	
	kharif season	***rabi season***
Ajnala	701.7	489.7
Chogawan	699.2	477.3
Gandiwind Saran at Amritsar	732.7	539.5
Harsha Chhina	700.7	487.5
Jandiala	700.2	467.3
Majitha	703.2	477.8
Rayya	702.2	495.8
Tariskka	706.0	488.3
Verka	701.7	450.2
	Barnala	
Barnala	728.7	539.0
Mahal Kalan	728.3	539.7
	Fatehgarh Sahib	
Amloh	601.2	547.5
Bassi Pathana	600.8	482.5
Khamanon	601.8	484.0
Khera	597.8	483.2
Sirhind	600.2	478.7
	Ferozepur	
Makhu	747.3	514.0
Zira	747.3	533.2
	Gurdaspur	
Batala	663.7	449.7
Dera Baba Nanak	654.8	457.7
Dhariwal	666.7	455.5
Fatehgarh Churian	658.7	445.0
Kahnuwan	660.0	454.2
Kalanaur	656.2	447.3
Qadian	666.7	455.5
Sri Hargobindpur	670.5	456.0
	Hoshiarpur	
Garh Shankar	499.3	465.8
Hoshiarpur I	520.7	476.7
Hoshiarpur II	496.2	474.2
Mahilpur	474.8	459.7
Tanda	620.7	487.7
	Jalandhar	
Adampur	648.3	503.7
Bhogpur	667.7	512.8
Jalandhar East	662.0	501.8
Jalandhar West	667.3	498.5
Lohian	666.7	498.0
Nakodar	655.3	489.2
Nur Mahal	673.8	497.5
Phillaur	679.8	512.3
Rurka Kalan	682.7	512.3
Shahkot	672.2	502.5
	Kapurthala	
Dhilwan	699.3	507.0
Kapurthala	672.8	500.5
Nadala	696.8	503.7
Phagwara	676.5	509.0
Sultanpur Lodhi	678.7	500.0
	Ludhiana	
Dehlon	677.3	500.0
Doraha	678.2	501.5
Jagraon	677.2	503.7
Khanna	677.8	504.3
Ludhiana I	677.5	499.3
Ludhiana II	677.2	500.8
Machhiwara	676.0	504.8
Pakhowal	677.5	503.2
Raikot	677.8	504.2
Samrala	676.8	506.0
Sidhwan Bet	675.7	502.3
Sudhar	677.3	503.8
	Moga	
Kot Ise Khan	731.8	529.8
Moga-I	732.0	528.0
Nihal Singh Wala	731.0	525.0
	Nawan Shahar	
Aur	619.3	483.5
Banga	611.2	485.2
Nawan Shahar	601.3	498.5
	Patiala	
Bhunarheri	643.3	499.2
Ghanaur	637.2	501.7
Nabha	645.2	503.0
Patiala	643.3	499.0
Patran	644.8	500.2
Rajpura	635.2	485.3
Samana	644.2	500.3
Sanaur	643.8	498.8
Bhunarheri	643.3	525.5
	Sangrur	
Andana	696.3	525.5
Bhawanigarh	696.0	503.8
Dhuri	699.8	526.3
Lehra Gaga	695.8	531.3
Malerkotla I	696.3	486.0
Malerkotla II	696.2	504.0
Sangrur	697.0	539.3
Sher Pur	697.0	529.3
Sunam	695.7	526.2
	Tarn Taran	
Bhikhiwind	733.0	541.7
Chola Sahib	728.0	541.8
Gandiwind Tatla at Chola Sahib	732.7	539.5
Khadur Sahib	732.2	538.8
Naushera Pannuan	733.3	541.2
Patti	731.5	540.7
Tarn Taran	732.2	539.5

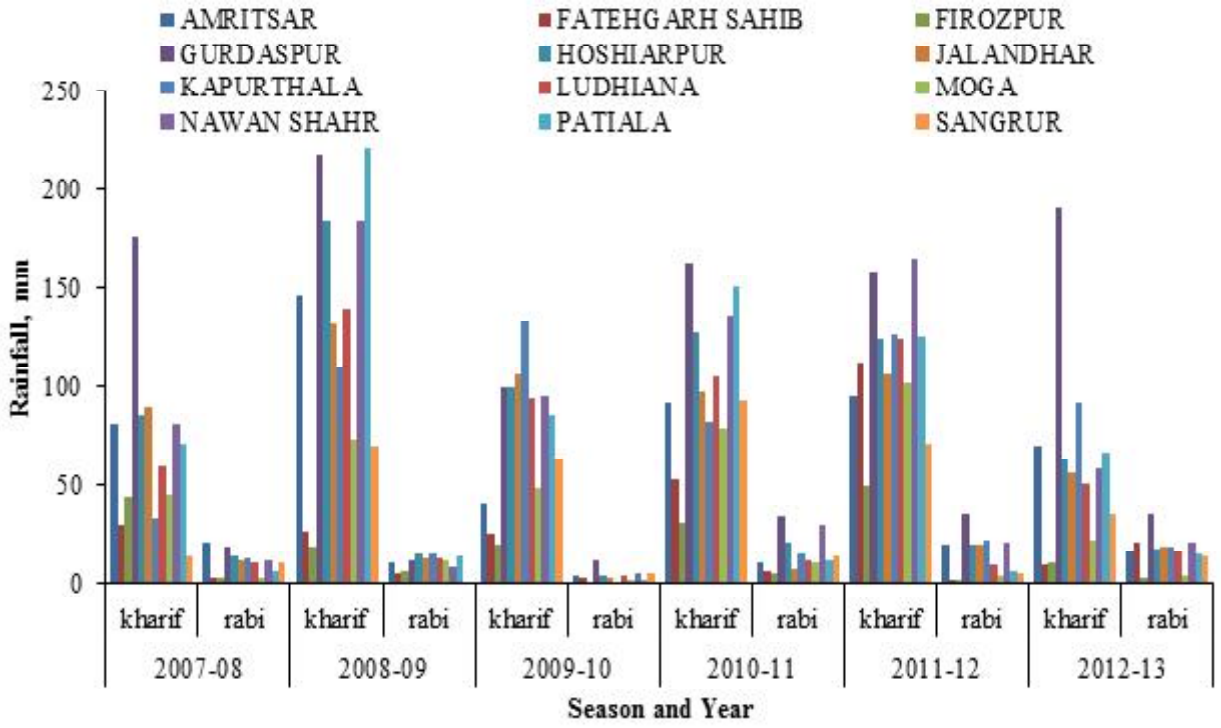

Fig 2: Average monthly rainfall of districts of central Punjab

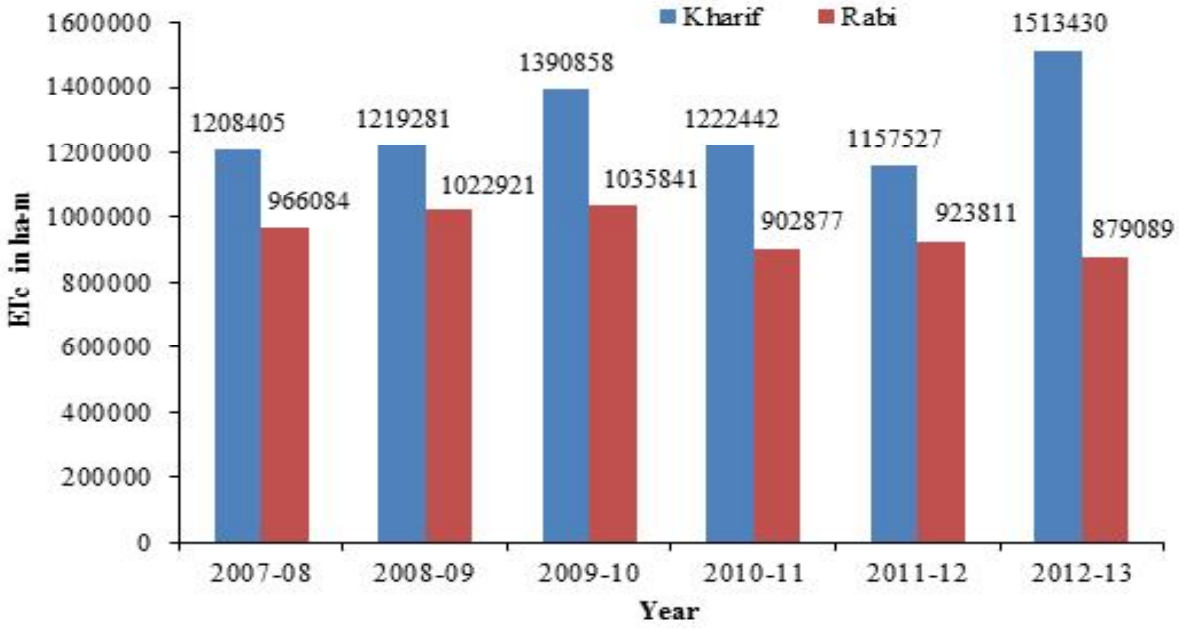

Fig-3: Chart showing average annual ETc for Central Punjab

Fig. 4 depicted ET_c distribution maps over the study period. The year wise map of ET_c for *kharif* season depicted the variations in ET_c over the study period. During the study period, ET_c demand in *kharif* season for most parts of central Punjab lies in the range of 600-750 mm. A variation was experienced during year 2009-10 when ET_c demand in most of the blocks lies in range 700-800 mm. This variation might be resulted due to the increase in maximum and minimum temperature for the months of June, July and August throughout central Punjab. In preceding years the average maximum temperature was about 35°C, but for year 2009-10, it rose to about 40°C.The year 2012-13 was the only year when ET_c demand rose to above 800 mm in many parts. This increase would again be attributed to the rise in maximum temperature to about 42°C.

The year wise map of ET_c for *rabi* season depicted the variations in ET_c over the study period (Fig. 5). In *rabi* season, ET_c demand for most parts of central Punjab during years 2007-08 to 2009-10 lies in range 500-600 mm. The consequent years 2010-13, certain decrease in ET_c demand

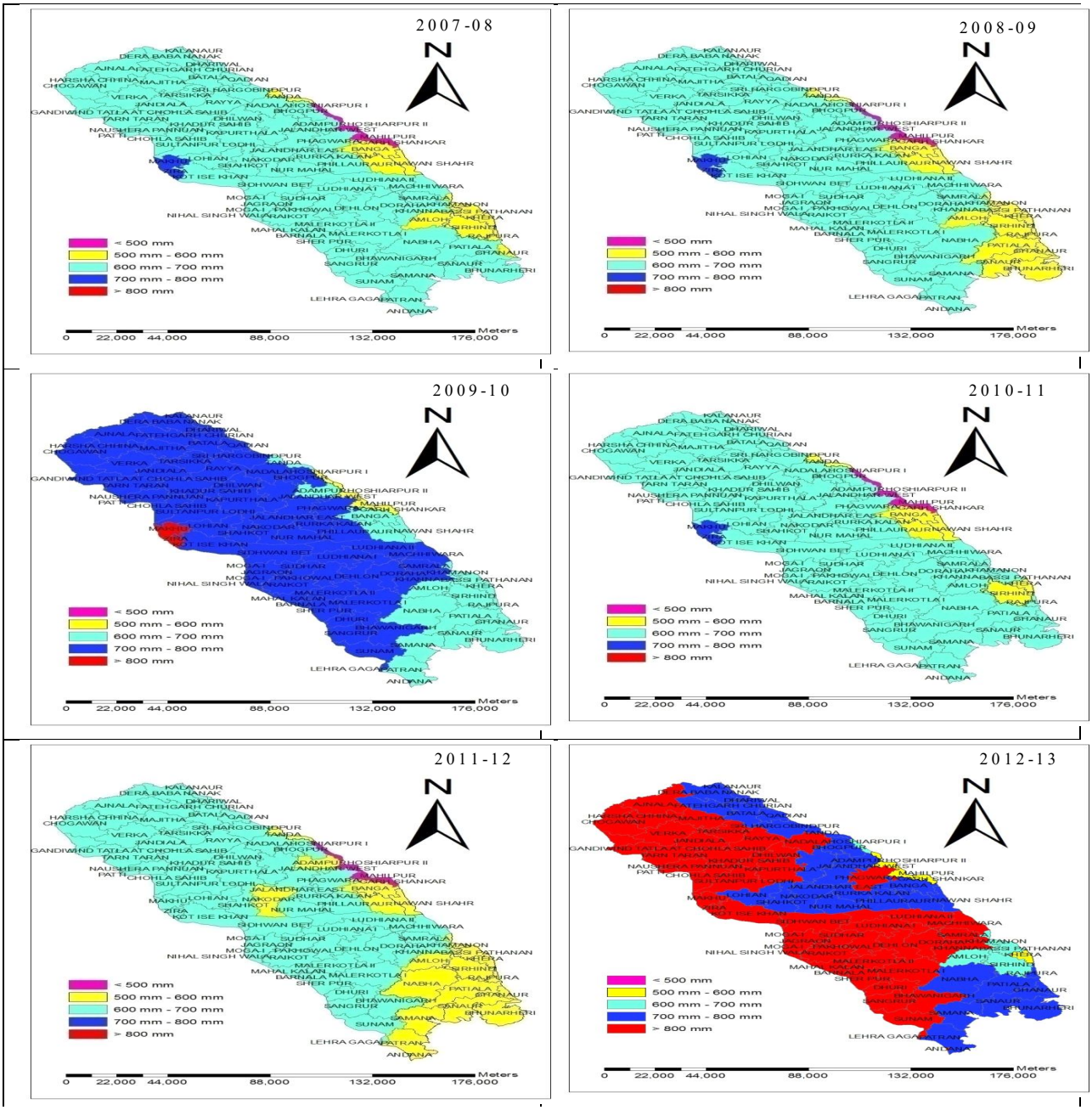

Fig 4: GIS maps of ET_c for *kharif* season from 2007-2013

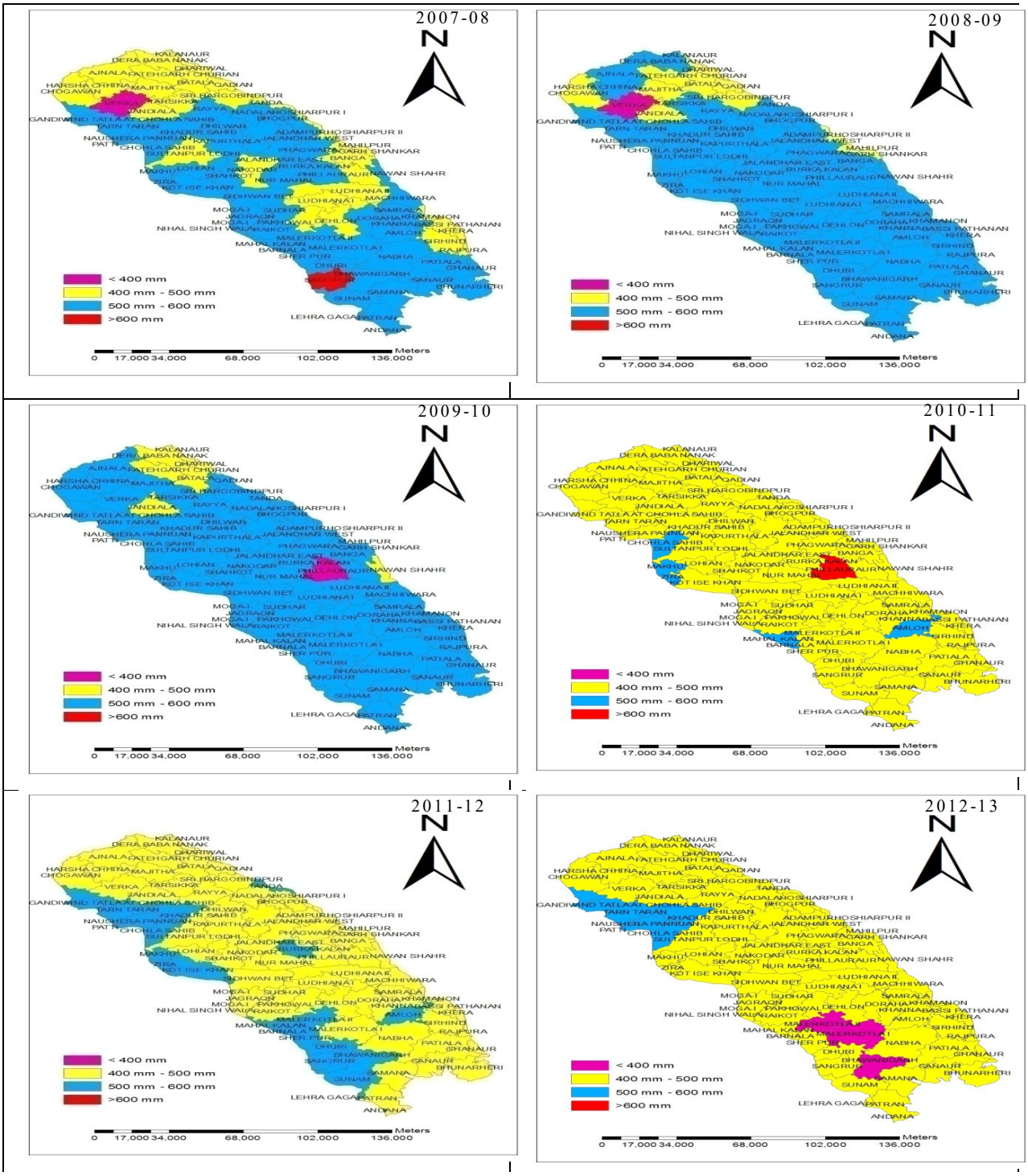

Fig-5: GIS map of ET_c for *rabi* season from 2007-2013

in most of the blocks was observed in the range of 400-500 mm. A close look on the temperatures for months of February, March and April revealed that the years 2010-13 experienced a decrease in maximum and minimum temperatures than the preceding years. This decrease in temperatures resulted in drop in ET_c demand. Detailed description of average ET_c (in mm) in all blocks of central Punjab was presented in Table 3.

CONCLUSIONS

This study concluded that maximum average water demand of Central Punjab is 24,26,700 ha-m. This is 55 % of total crop water demand of Punjab.In block wise

assessment, maximum water required (747.5 mm) in *kharif* season was in block Makhu and Zira of Ferozepur district and in *rabi* season, block Amloh needed more water (547.5). The ET_c value showed the crop water requirement, the average ET_c demand of 501 mm for *rabi* and 670 mm for *kharif* season were quite high as compared to average annual rainfall of 709 mm. which is unevenly distributed throughout the year and the effective rainfall is even less. So, there is a need to shift from high water requiring crop to low water requirement crops and grow more of short duration crops. Moreover the ETc map can be used to identify the blocks of high water requirement and accordingly the schedules of canal operation can be decided.

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