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"Spatial variability of sugar cane (*Saccharum officianarum*) irrigation requirement mapping for Arjo-Dedessa sugar factory and its surrounding, Southwest of Ethiopia."

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Abstract

The continuous dependence on rainfall causes a yield reduction and leads to a risk for food security in the world as well as in Ethiopia. For sustainable food security and development, production and productivity improvement it needs to shift the rainfed agricultural production to irrigated agricultural production. The raw matter for the production of the sugar is a sugar cane crop and now a day because of erratic rainfall irrigation water resources planning and management is critical for sugar cane production. Therefore, this study was initiated with the major objective to study the variation of irrigation requirement of sugar cane and to prepare the spatial map of irrigation requirement of the crop for Arjo-dedessa sugar factory and the surrounding area for water resources planning and management. For conducting the study Arc GIS 10.4.1, CROPWAT 8.0, and XLSTAT software were the materials used. Shape file and Digital Elevation Model (DEM) data were collected from Ministry of Water Irrigation Electricity and, climate data were collected from National Meteorological Service Agency. For calculating the irrigation requirement, the crop water requirement was calculated using the CROPWAT 8.0 model and after that the irrigation requirement was calculated by deducting the effective rainfall from the total crop water requirement. For mapping, a linear regression equation was developed between observed data and station's location. The inverse distance weight (IDW) map reveals that the irrigation water requirement of sugar cane in the agro- ecology of Arjo Dedessa and its surrounding was in the range of 464.34 mm - 961.57mm depth of water spatially. It was high in the Northern part of the study area and low in the Western and Eastern part of the study area. The temporal variation of the crop irrigation requirement reveals that, the crop does not require irrigation during the months of May, June, July, August and September in all parts of the study area. A more experimental research has to be conducted in order to determine the irrigation schedule and the water use efficiency of the crop.

Key words: depth of water, Irrigation, mapping, mm, sugarcane

1. Introduction

1.1. Background and justification

Even though the potential increase in irrigation water uses and land resources are limited, still irrigation plays an important role in food production, food self-sufficiency and food security. The continuous dependence on rainfall will cause a yield reduction and cause a risk for food security in the world as well as in Ethiopia (Awulachew *et al*, 2007), so changing the dependence on rainfall to irrigation technology can be an option for crop production. According to FAO (2007), the average crop yields per hectare from irrigated land increases 2.3 times higher than the yield produced by rain fed agriculture. There was an occurrence of infrequent crop failures followed by dry spells, occurrence of severe droughts and significant soil erosion due to non-uniformity of rainfall which may reduce the potential productivity of farmlands (Awulachew *et al*., 2010). The low level of rain-fed agriculture performance could be attributed to the erratic nature of rainfall and deteriorating soil fertility and slow adoption, and lack of appropriate technologies (Hordofa *et al*., 2012). For sustainable food security and development, production and productivity improvement and for drought tolerance it needs to shift the rainfed agricultural production to irrigated agricultural production.

According to Tayler (2005), irrigated agriculture plays a significant role in reaching the broader development vision of the country in achieving food security, poverty alleviation and improvement in the quality of life that depend on agriculture by providing plants with sufficient water to prevent stress that can cause yield reduction. In line with this, Ethiopia is increasingly implementing irrigation developments more than ever to supplement the rain-fed agriculture (reference). It aims to increase agricultural productivity and diversify the production of food and raw materials for agro-industries like sugar factory and ensure that agriculture plays a pivot for driving the country's economic development (Mekonen, 2011).

Sugar development is one of the industries that the Ethiopian government is working aggressively to supply the ever-increasing demand of sugar. Its involvement begins by considering the country's ample potential in human and natural resources that enable the nation to develop the sugar sector by increasing productivity and rendering it towards export orientation (IOE, 2019). Among the huge planned industries, the Arjo-Dedessa sugar factory is one of them. But Weather and climate related events, i.e., growth environment of atmospheric, temperature, precipitation, and other extreme weather are the key factors for sugarcane production. The sugar cane crop production and productivity, which is used as an input for sugar production, was low because of erratic rainfall, technical problem, and irrigation water management (Equbay, 2015; Dejene, 2013; Tena *et al*., 2016).

In Arjo-Dedessa sugar factory and the surrounding areas there are farmers that cultivate sugarcane crop for local use. The raw matter for the production of the sugar is a sugar cane crop and now a day since there is a water scarcity (Seleshi *et al*., 2007; Pereira *et al*., 2004), and erratic rainfall that can cause a water stress (Wolde Amlak, 2009), irrigation water resources planning and management is critical for sugar cane production for other crops generally.

The availability of meteorological station in the locality is necessary to measure the climate parameters like the precipitation, maximum and minimum temperature which are important for water resources planning and management. However, it is not available in all parts of the area. Hence in order to plan an irrigation water management in the area it can be possible to use the available meteorological data and interpolate in order to get the unavailable data and prepare map. Since irrigation requirement of a crop varies with the climate of the area (Jocik, 2004; Kiptala *et al.*, 2013), it needs to study the spatial and temporal variation. Therefor this study was initiated with the major objective to study the variation of irrigation requirement of sugar cane and to prepare the spatial map of irrigation requirement of the crop for Arjo-dedessa sugar factory and the surrounding area for water resources planning and management.

2. Material and methods

Description of the study area

The study area is located at South Western Ethiopia of Oromia Regional State including some parts of Eastern Wollega, some parts of Ilu Ababora and some parts of Jimma Zones that surround the Arjo-Dedessa sugar factory at 540 kilo meter from the capital through the route of Addis Ababa-Jimma-Nekemt roads. The altitude of the area is 1,350 meters above mean sea level. Geographically, it is found $7^0$36'00" up to $9^0$36'00" North and $35^0$32'00" up to $37^0$34'00"East.

The study areas have mean annual rainfall of 1400 millimetres. Its rainy season extends from May to October. The Monthly mean maximum temperature varies from 21.16^{o}C up to 33.75^{o}C and monthly mean minimum temperature varies from 7.01^{o}C to 14.89^{o}C. The rain fall distribution of the study area reveals that, the distribution is not uniform in some months the rain fall is very low and even no rainfall up to four to five months continuously and in some months there is a continuous rainfall mainly during the summer season.

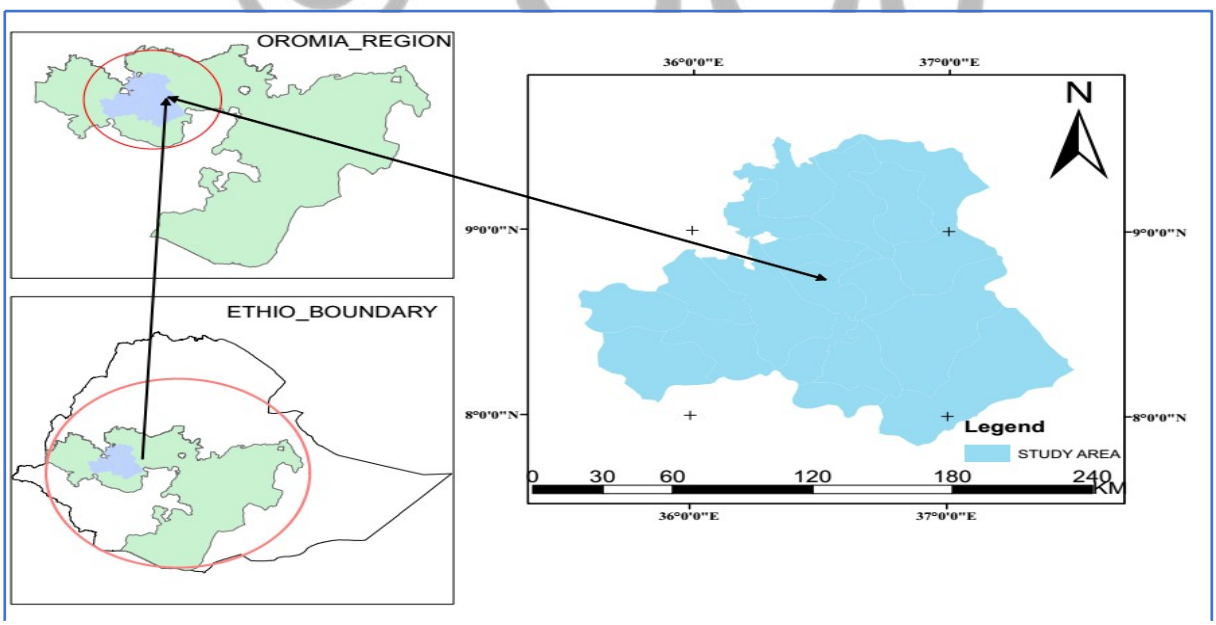

Figure 1. Location of the study area boundary

Materials and methods

For conducting this study, the materials used were the Arc GIS 10.4.1, CROPWAT 8.0, XLSTAT software. GIS was used for mapping the spatial variability of the irrigation water requirement of the crop. In order to fill the missing data, xlstat2019 software was used since the meteorological data has

a missing value (Statical, 2019). CROPWAT 8.0 model was used to calculate the irrigation Water Requirement of the crop after deducting the effective rainfall that were collected from each meteorological station (equation 1 and 2).

The necessary input data to estimate the irrigation requirement which were used as an input for the CROPWAT 8.0 model were the properties of the crop such as planting date, harvesting date, crop coefficient (KC) for a ratton sugar cane crop were collected by using the Field visit, inspection and observation and finally adapted from FAO-56. Shape file and Digital Elevation Model (DEM) were collected from Ministry of Water Irrigation Electricity and, climate data were collected from National Meteorological Service Agency.

Fourteen (14) meteorological stations in Oromia regional states that surround the Dedessa River and the Arjo Dedessa sugar factory namely the Abasan Joger, Anger, Arjo, Atnago, Bedele, Chora, Dedessa, Dembi, Limu-Genet, Metu-Hospital, Nekemite, Toba, Yanfa and Yayo stations were delineated (figure 2) and from these, meteorological data from ten (10) stations namely Anger, Nekemt and Arjo in the Northern; Bedele, Yanfa and Dembi in the Southern; Atinago and Limu-Genet in the Eastern; and Yayo and Chora station in the Western of the study area (Arjo-Dedessa Sugar Factory) were used for analysis. The basic data quality checking mainly filling the missing data, checking the consistency of the rainfall and checking homogeneity of the data were done as shown in figure 3 and 4 below.

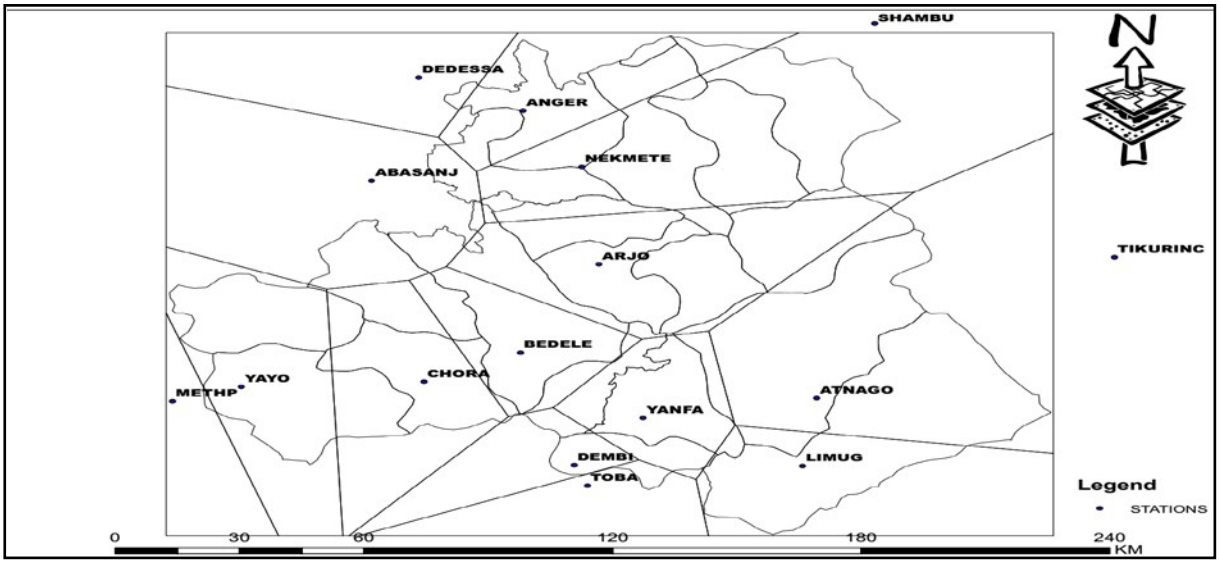

Figure 2. Delineated meteorological station that surround the boundary of the study area

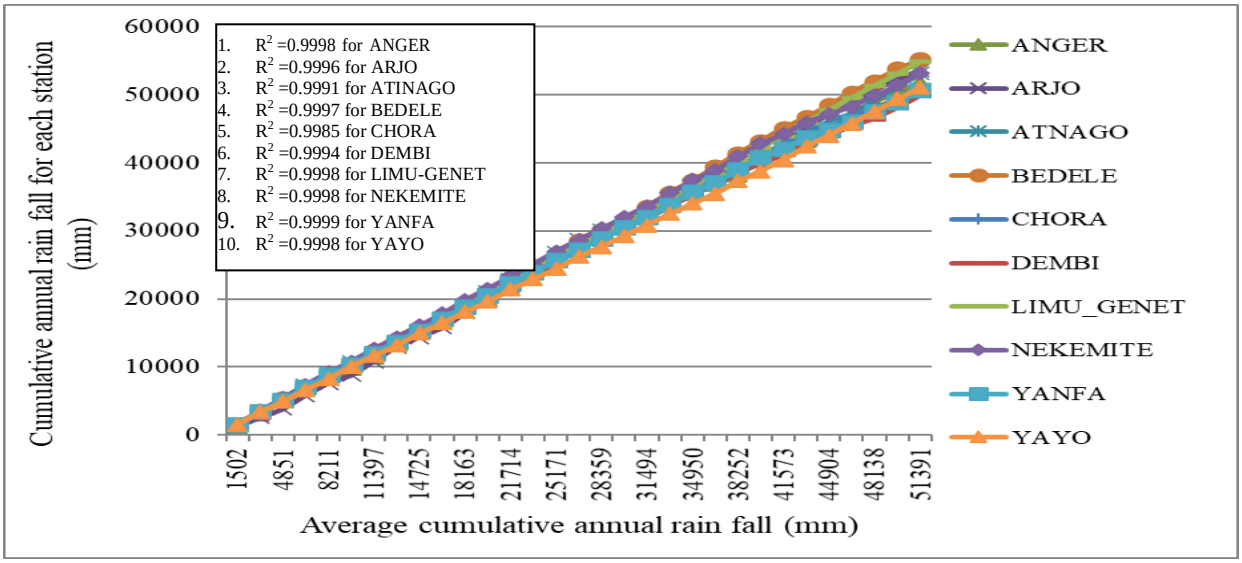

Figure 3. Double Mass Curve (consistency test) for the Stations of the study area

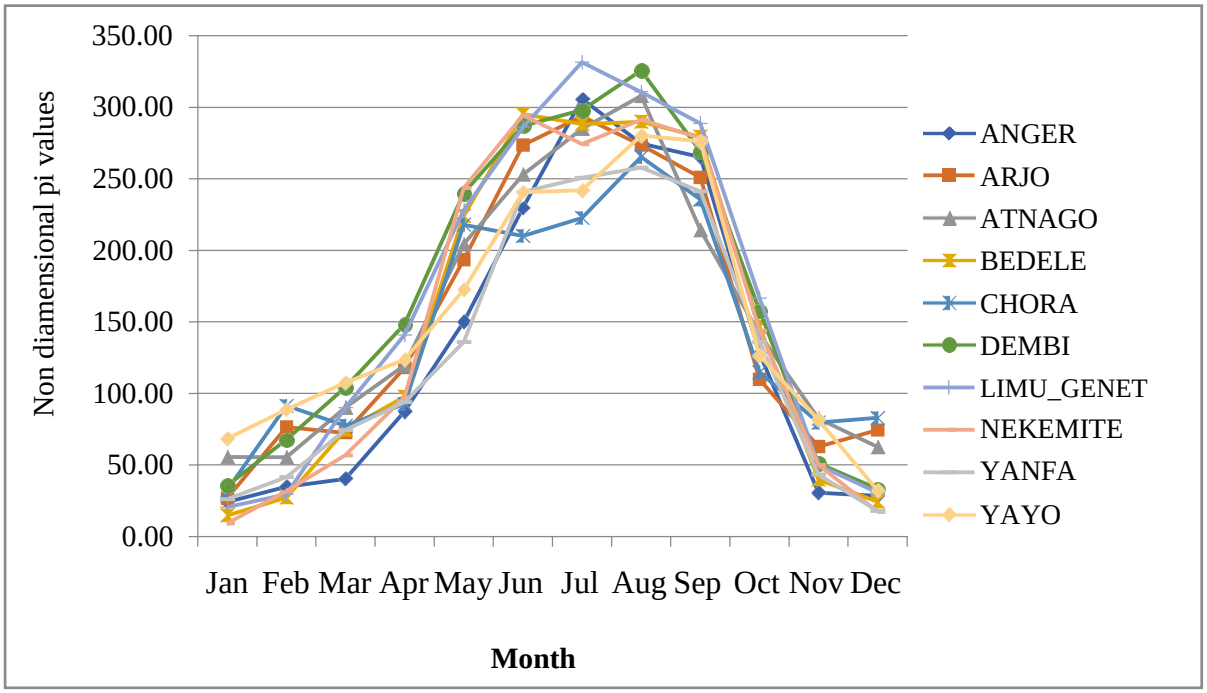

Figure 4. Non-dimensional plot of stations (Homogeneity test)

For calculating the irrigation requirement first, the crop water requirement was calculated using the CROPWAT 8.0 model and after that the irrigation requirement was calculated by deducting the effective rainfall from the total crop water requirement.

$$ETc = Kc \times ETo \quad (1)$$

$$IWR = ETc - Peff \quad (2)$$

Where: ETC- Crop evapotranspiration (mm/period)

Peff - is effective rainfall (mm)

IWR- is irrigation water requirement in (mm/period)

Kc- is crop coefficient

ETo- reference evapotranspiration (mm/day)

For mapping, a linear regression equation was developed between observed data and station's location. Using the linear regression equations, the residuals of irrigation water requirement were estimated as the difference between observed and predicted values at gage locations. Then the value was interpolated using ordinary kriging method over the entire region. Using DEM and regression equation, station-based data was further extended to 5 km spatial grids. Then the IWR for each month starting from January to December were interpolated to 1km×1km spatial resolution by using gstat package of the geostastical tool of the GIS software. The final map of irrigation requirement was directly interpolated without considering elevation effects. Finally, the reliability and applicability of the geostastical tool for the mapped irrigation water requirement (ETc) were validated by the measured data and predicted value.

3. Result and discussion

Irrigation requirement of sugar cane (*Saccharum officianarum)*

Spatially the irrigation water requirement of the sugar cane (*Saccharum officianarum*) in the study area ranges from 464mm to 962mm annually. The seasonal irrigation requirement at Anger area was 961.60mm, it was 488.60mm at Arjo station and at Nekemt area 826.40mm depth of water in the Northern part of the study area. There is more than 50% irrigation water requirement difference between Anger and Arjo area this is because of the climate variability and altitudinal difference. At high elevation area the irrigation requirement is relatively low because of high amount of rainfall.

At the southern part of the study area the irrigation water requirement depth was 647.40mm, 646.80mm and 775.20mm for Bedele, Dembi and Yanfa area, respectively. The irrigation water requirement of the crop is relatively similar in the southern part of the study area. This similarity is because they are on a relatively similar altitude and of the same climate. At the Western part of the study area the irrigation water requirement depth was 532.80mm and 631.80 mm for Chora and Yayo area, respectively. The irrigation water requirement was 464.30mm and 699.80mm depth of water for Atinago and Limu-Genet area at the Eastern part of the study area.

There was a spatial variation on the seasonal irrigation requirement of the crop at the Northern, Southern, Western and Eastern part of the study area. In the study area since the rainfall is enough, the crop does not require irrigation at the initial and development stage. In the Northern part of the study area namely Arjo, Anger and Nekemite area the irrigation requirement was 345.2mm and 143.5mm, 603.3mm and 358.3mm, and 526.4mm and 300mm depth of water, for the mid-season and late season, respectively. At the Southern part of the study area namely Bedele, Dembi and Yanfa the requirement was relatively low and was 434.7mm and 212.5mm, 469.1mm and 177.7mm and 504 mm and 269mm, respectively at the mid-season and late season, respectively. At the Western part of the study area the depth of water was 349.8mm and 183mm for Chora area and 452mm and 179.6mm for Yayo area for the mid and late season, respectively. At the Eastern part of the study area the irrigation

water requirement of the crop was 320.6mm and 143.8 mm for Atinago area and 484.3mm and 215.5mm depth of water for Limu-Genet area for the mid and late season, respectively.

The temporal variation of the crop irrigation requirement reveals that, the crop does not require irrigation during the months of May, June, July, August and September in all parts of the study area. Hence, the amount of rainfall in the study area was enough for the crop in these months temporally. From this it is understood that there is no problem of rainfall amount in the south western part of Ethiopia, the problem is on the distribution. The rainfall is high during the summer season.

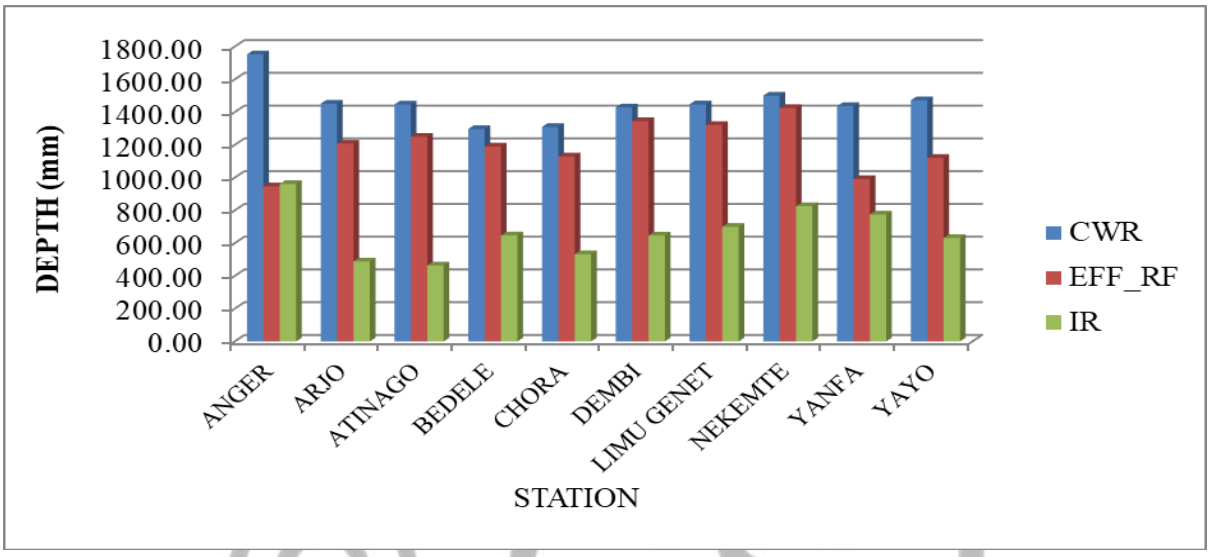

Figure 5. Crop water requirement, irrigation requirement and effective rainfall of the stations

The expected occurrence of drought in most part of the country has an impact on the production and productivity of agricultural crops. Even though the sugar cane is a drought tolerant crop it is a crop that requires high amount of water and in this case, it is difficult to meet the required amount of water through rainfall, hence it demands irrigation. In south western part of the country there is a high amount of rainfall distribution, but the highest amount of rainfall was in the summer season of the year mainly in June, July, August, and September. In the remaining period for the full development of the crop water is necessary and must be filled by irrigation.

Irrigation is one means for a good farm husbandry, better land utilization and stable and higher crop production. Sustained growth and dynamism in agriculture is a fundamental necessity to meet the increasing demand for food and other products in view of the growing population. Irrigated agriculture plays a major role in achieving the broader development vision of the country in achieving food security, poverty alleviation and improvement in the economic income. Irrigated agriculture provides plants with sufficient water to prevent stress that can cause reduced yields or poor quality of harvest of the crop.

Irrigation water requirement mapping of the study area

The inverse distance weight (IDW) map reveals that the irrigation water requirement of sugar cane in the agro- ecology of Arjo Dedessa and its surrounding was in the range of 464.34 mm

- 961.57mm. It was high in the Northern part of the study area and low in the Western and Eastern part of the study area (Figure 6 below). The co-relation between the measured and predicted value by geostatsical tool which is 0.67 also signify that the estimated irrigation requirement of the crop is in the acceptable range (figure 7).

The prepared spatial map has a great advantage to be applied in unsampled sites, i.e, areas that has no meteorological station or if the meteorological stations are not functional.

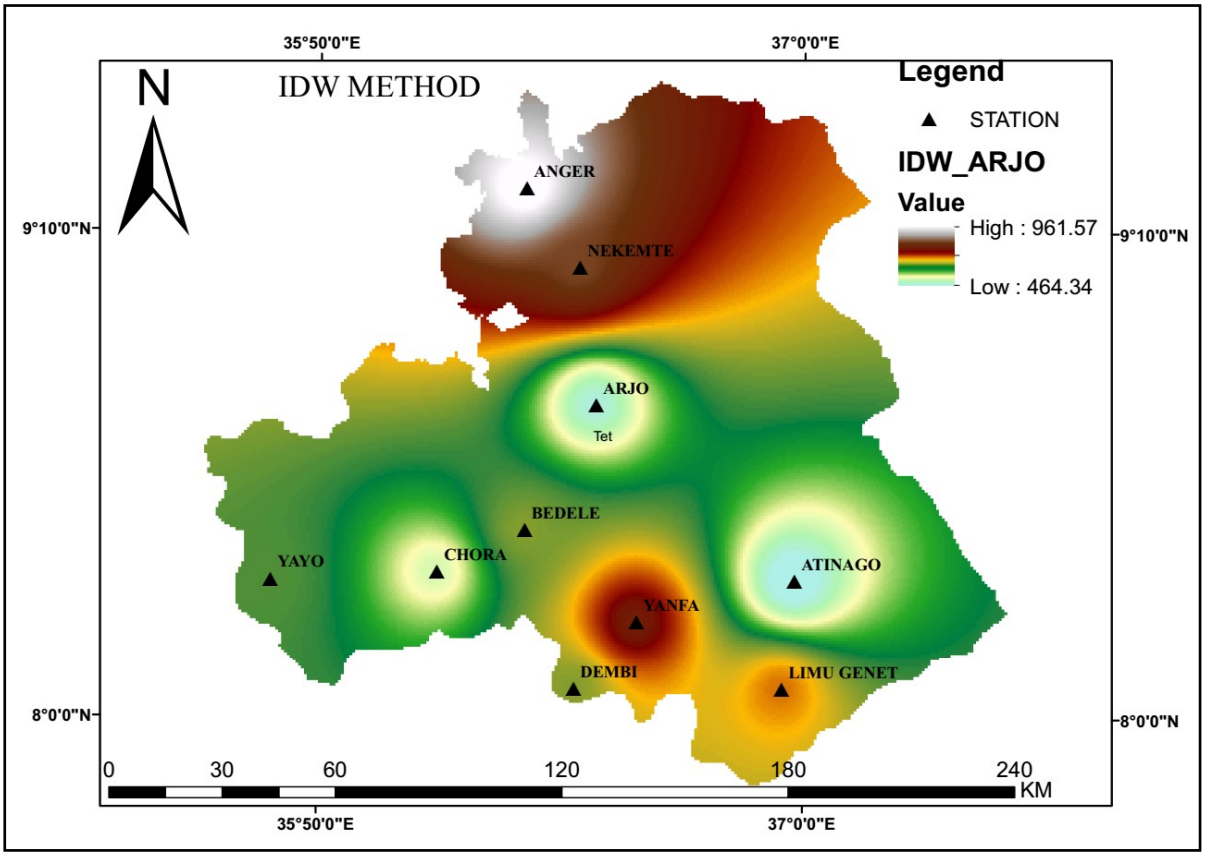

Figure 5. Irrigation requirement of sugarcane in the study area using the inverse distance weight method.

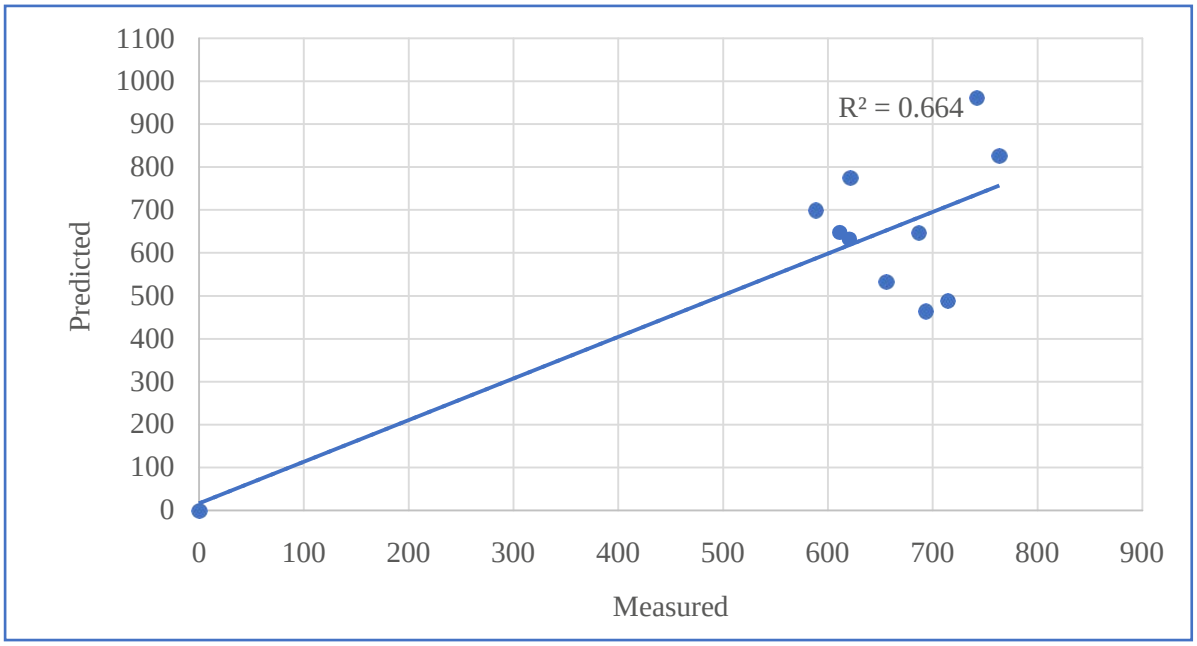

Figure 7. Validation of the irrigation requirement using the inverse distance method

4. Conclusion and recommendation

Agricultural production can be improved through the use of irrigation and this can be achieved by determining the crop specific characteristics of irrigation requirement of the crop. Therefore, the determined crop and water requirement of the crop can be applied for water resources planning and management in the factory. It can also assist the farmers and private investors to manage the irrigation water and hence to produce more.

Farmers that depend on rain-fed farming are restricted to plant during the period of the year that rain falls. By relying on rain-fed system of agriculture, farmers are susceptible to low yields whenever rainfall is not as expected. Farmers that plant during the late planting are also susceptible to insect infestations on farms, as some pests of plants can be avoided by planting at a particular period of the year. All these mean that farmers are unable to make optimum profits from farm. Therefore, this study can also initiate farmers to practice irrigation.

Since there is an ample amount of rainfall in the summer season, it is recommended

- To harvest the water during the summer mainly from May to September in order to use during the dry period.
- Based on the topography of the study area it is recommended to practice furrow irrigation method.

- A more experimental research has to be conducted in order to determine the irrigation schedule and the water use efficiency of the crop.

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