Estimation of the Reference Evapotranspiration across the Helmand River Basin, Afghanistan

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Abstract- Helmand River basin (HRB) is the largest river basin in Afghanistan in terms of geographical area while the third in terms of surface water availability after Kabul and Amu River basins. The topography of this basin is characterized by high mountains, plateaus and deserts, which influence the hydrology of the region. Helmand River is the main source of water for irrigation in the basin that plays a critical role in sustaining agriculture and livelihoods in the region. In addition to an inefficient water management system, the Helmand River Basin (HRB) faces the challenges of being an arid region as well as exposed to the negative impacts of climate change and droughts etc. This dual exposure not only anticipates an exacerbation of water scarcity but also foresees reduced agricultural yields and heightened conflicts arising from increased competition for water resources among various consuming sectors; climate change has drastically reduced the water availability in this basin and therefore, has been the main driver of conflict between Afghanistan and Iran. Owing to the pre-existing water sharing agreement between the two countries, data scarcity about the biophysical processes in this basin has further added to the misunderstanding between the two riparian countries. In order to contribute to the knowledge pool on water resources in this basin, it is important to assess the increasing atmospheric demand for water, for which Reference Evapotranspiration (ET0) is usually used as a proxy. This study presents a detailed investigation into the estimation of the ET0 across the HRB by using ET0 Calculator, developed by the Food and Agriculture Organization of the United Nations. The meteorological data (temperature, humidity, wind speed, and solar radiation) used in the ET0 Calculator was derived from the CLIMWAT database. The ET0 is a critical parameter in understanding the water dynamics within the HRB. The results demonstrated a higher ET0 at Kandahar province where the total mean annual ET0 was (2068.58 mm/year) while the lowest was in Ghazni province (1542.81mm/year). Similarly, July is experiencing the highest ET0 (260.4 mm/month) while the lowest ET0 was in the month of January (55.122 mm/month).

I. Introduction

Evapotranspiration is a combined process of evaporation from the soil surface, capillary fringe of the groundwater, and water bodies as well as transpiration from plants. Evapotranspiration is a significant component of the water cycle and plays a vital role in the water balance of ecosystems (Allen et al., 1998). It is particularly important in the water and energy balance on the earth's surface, as well as in agricultural and irrigation activities. Evaporation accounts for approximately 70% of the water loss from the earth's surface (Nag et al. 2014). There are various types of evapotranspiration having variation between each other; one of it is Reference Evapotranspiration (ET_0), which is measured with respect to a reference surface having no deficiency of water with uniform grass surface (Alfalfa). It is an essential element of the hydrological cycle, energy, and water balance by playing a crucial role in the fields of agriculture and hydrology. Regardless of the crop variety, growth, or management techniques, ET_0 monitors atmospheric evaporation demand; estimation the rate of ET_0 is the elementary stage for planning, designing and monitoring for management of water resources, irrigation schedule, crop output, and environmental assessment (Martins et al., 2017).

For decades, Afghanistan has been experiencing prolonged unrest, leading to a scarcity of data across all the river basins (Akhtar et al., 2022). This scarcity makes it challenging to technically evaluate the demand and supply of water resources for the most resource-consuming sectors and accordingly manage its water resources. Besides, the Western and Southwestern part of Afghanistan where Helmand River basin is located is extremely prone to the impacts of climate change that may amplify the tensions between the two riparian states. Furthermore, the absence of reliable data has resulted in an extended distrust between Afghanistan and Iran, stemming from a pre-agreed and signed treaty concerning the water of the Helmand River. Recently, the situation over the conflicting amount of

water received by Iran has escalated to the point where military equipment and personnel have been deployed in the border regions by both the countries. The complexity of such a situation could be mitigated with the assistance of available data and its rational and scientific explanation. As a very critical parameter for understanding the water balance situation in a region, estimation of the ET_0 is critical for water resources management. In this study, we have estimated the ET_0 across the HRB while using the global dataset.
There are several methods in use for measuring ET_0, however majority of them are only applicable under specific meteorological and agronomic conditions which cannot be used in situations other than those for which they were developed (Allen et al., 1998). However, the Food and Agriculture Organization of the United Nations recommends Penman–Monteith (PM) equation that has gained acceptance as a standard method for estimating reference evapotranspiration. It can be used globally without any local calibration because it incorporates both physiological and aerodynamic parameters and has been validated in different environments using accurate lysimeter measures (Allen et al., 1998). The calculating process for the physically based PM equation necessitates multiple accurate meteorological measurements of wind speed, solar radiation, relative humidity, and air temperature but physical data scarcity has been one of the key problem faced by the HRB. Thus, to solve this issue in the absence of physical data one of the alternative is to use remote sensing or global datasets, which are available in free domains. Therefore, we used CLIMWAT 2.0 , together with CROPWAT to tackle the issue of data scarcity. We only retrieved the data covering the Helmand River Basin. The CLIMWAT 2.0 contains agro climatic data from over 5000 stations around the world and was produced jointly by the FAO's Water Development and Management Unit and the Climate Change and Bioenergy Unit.

1.1. *STUDY AREA*

The Helmand River Basin encompasses parts of southeast Iran, the southern half of Afghanistan, and tiny areas of Pakistan; it is the largest river basin in terms of area. There are 306,493 km^2 in the basin (without non-drainage areas of 40,914 km^2) and almost 6.5 million people who live in Afghanistan, Iran, and Pakistan (Whitney, 2006). This river basin is also dry to semi-arid, with hot summers and chilly winters. It is divided into several sub-basins, each with unique characteristics. Compared to other river basins, it is therefore more vulnerable in terms of its exposure to drought and the impacts of climate change (Van Beek et al., 2008). The river basin also faces a number of other difficulties, such as a lack of data and limited development interventions because of protracted insecurity. In this study, we used data from six stations which are shown in (Figure 1).

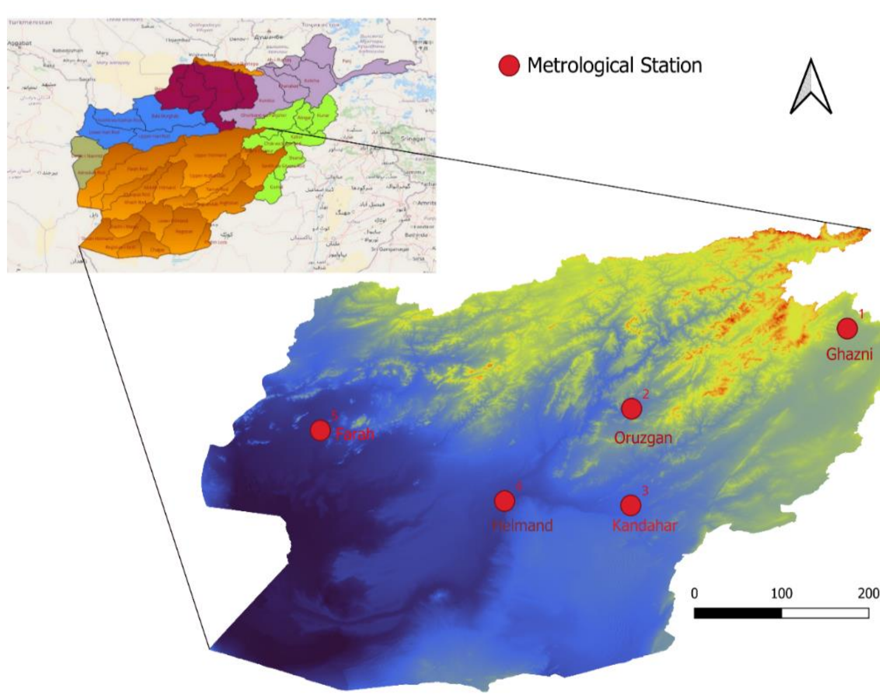

Figure 1: The study area map (Helmand River Basin, Afghanistan)

2.1 Climate

2.1.1. Precipitation

The precipitation received by the HRB is mainly in the form of rainfall with limited contribution from the snow. The data retrieved from CHIRPS Landsat (with a spatial resolution of 4.8 km) from (2000-2022) and it shows that precipitation falls within the months of October to May, whereby the highest average precipitation had been is being received in March that amounts to around (39.7 mm/month). The driest months have been June-October (Figure 2). The mean annual precipitation of around (i.e. 178.2 mm/year) (Figure 3). As show in the (Figure 3) the highest precipitation was experienced in 2019 (i.e. 309 mm/year) while the least precipitation was in 2021 (i.e. 96.7 mm/year).

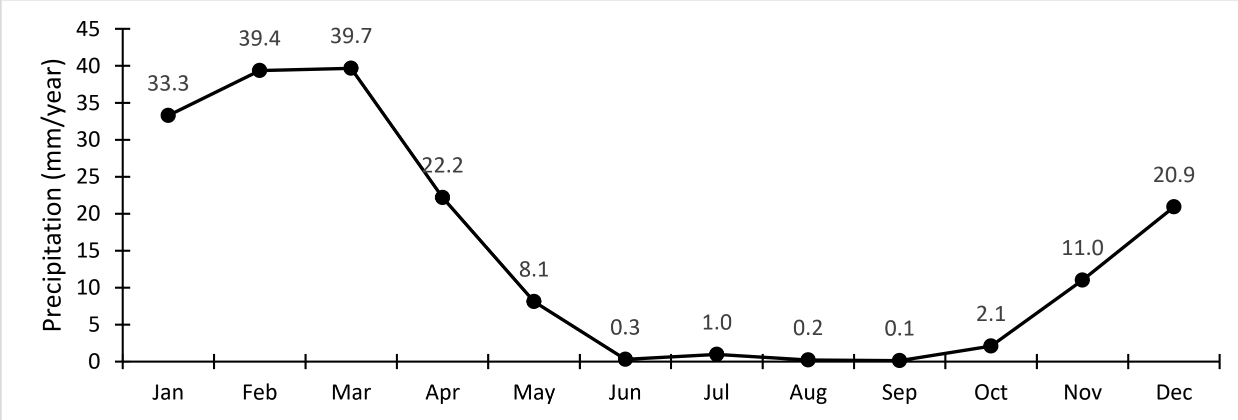

Figure 2: Mean monthly precipitation profile of the Helmand River Basin.

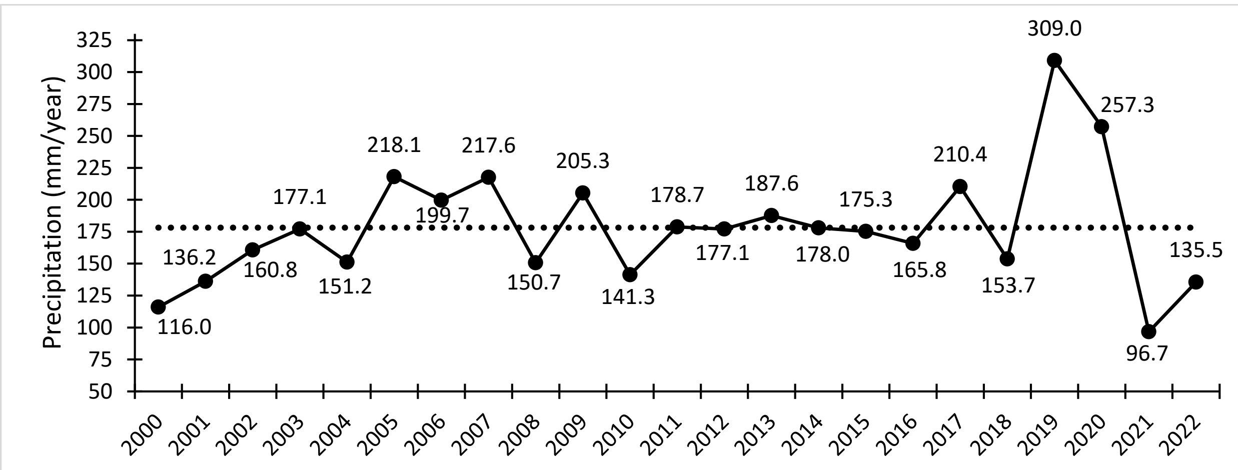

Figure 3: Historical variation of mean annual precipitation across the Helmand River Basin.

2. 1.2. Temperature

Temperature is a crucial parameter for ET_0 estimation, any increase or decrease in temperature affects the ET_0 in the same way. Typically the months of June-August are the warmest.While the coldest months are December and January (Figure 4). The historical mean annual temperature across the HRB was 16.33 ^{0}C. The lowest temperature was in 2012 (15.3 ^{0}C).While the highest precipitation was experienced in 2021 (17.6 ^{0}C). There has been increase in the mean annual temperature with respect to the historical mean (Figure 5).

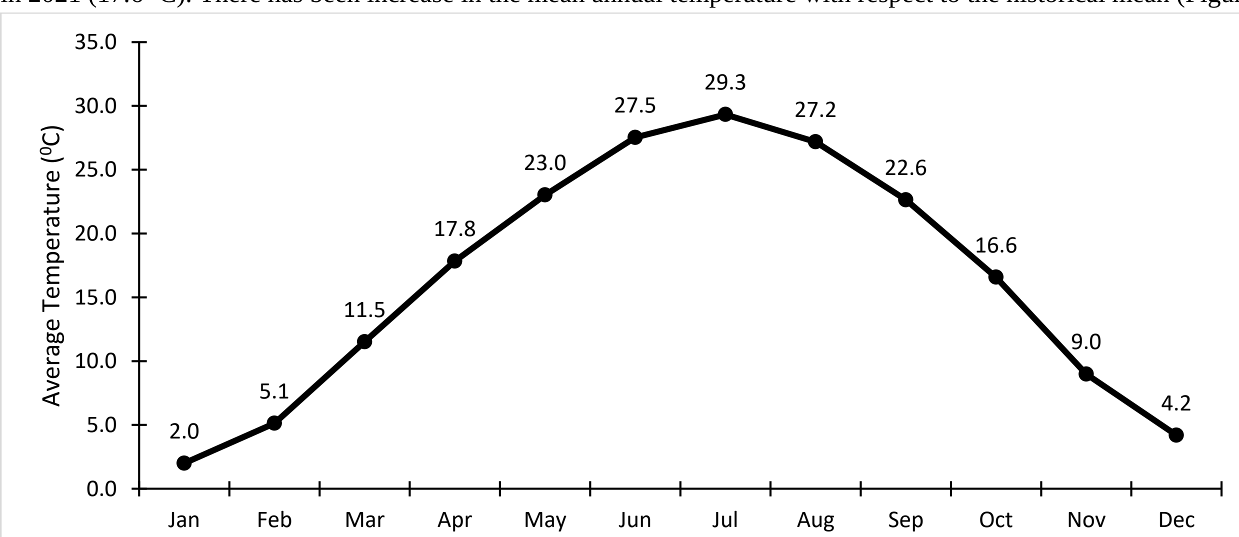

Figure 4: Mean monthly temperature profile of the Helmand River Basin

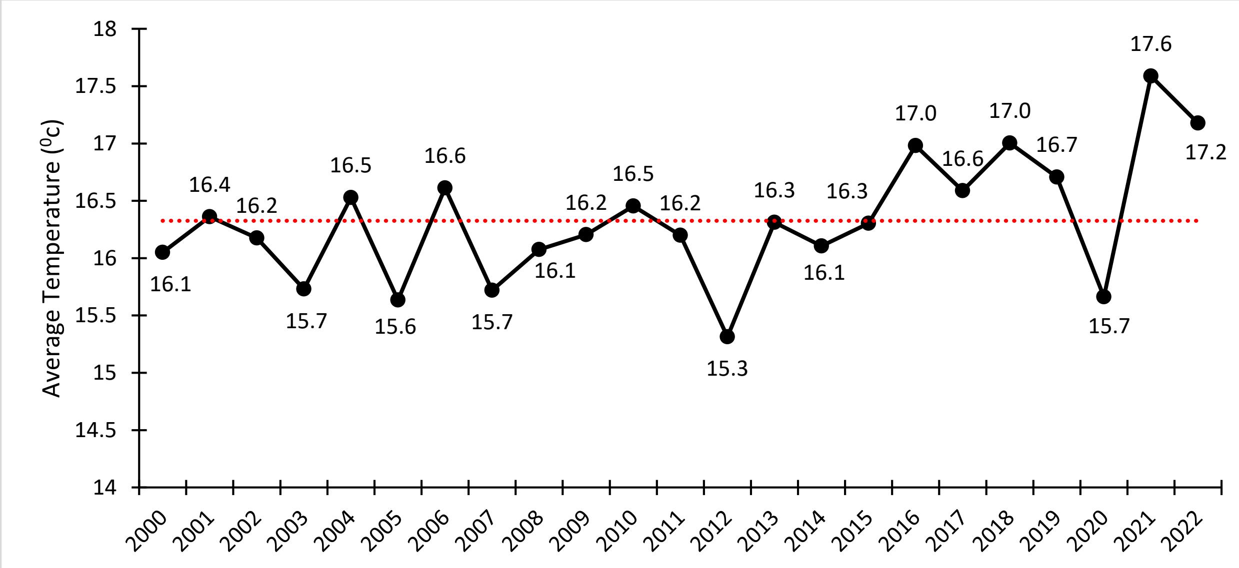

Figure 5: Historical variation of mean annual temperature across the Helmand River Basin

2. 2 Land Use And Land Cover

Helmand river basin is vital for agriculture with irrigation source being supported by the water from Helmand River. In this, dry area, irrigation is necessary to maintain crop production but water scarcity, droughts, soil degradation, and sporadic wars are problems that this region suffers from. According to the FAO Land cover atlas of Afghanistan (FAO 2016), the total irrigated area of the HRB is around 5.4%, water body constitutes around 3.9% while 43.1% accounts for Barren land and 35.7% for rangeland.

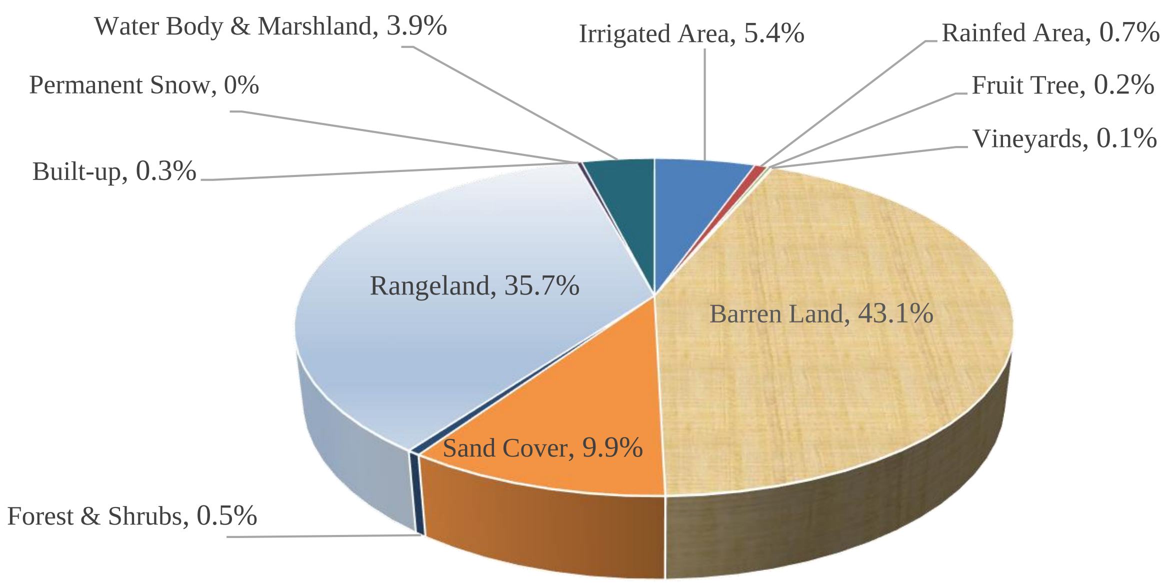

Figure 6: Land use and land cover statistics of Helmand River Basin (Source: FAO Land Cover Atlas of Afghanistan, 2016)

1. MATERIALS AND METHODS

3.1 *Methodological Framework*

In this study, meteorological data from six stations were collected while using the CLIMWAT database (FAO. Grieser, 2006). CROPWAT 8.0 (FAO Swennenhuis, 1999), based on FAO 56 paper (Allen et al. 1998) was used to calculate ET_0. The methodological framework for ET_0 estimation is given below in figure (7). We retrieved the meteorological data from CLIMWAT 2.0, it included temperature, wind speed, sunshine hours, relative humidity and relative rainfall. The crop physiology data i.e. crop phenology, crop coefficient, root zone, crop yield coefficient was adopted from the literature and soil texture data was also taken from the literature already provided in the manual for CROPWAT. Upon entry of this dataset, the CROPWAT simulated ET_0.

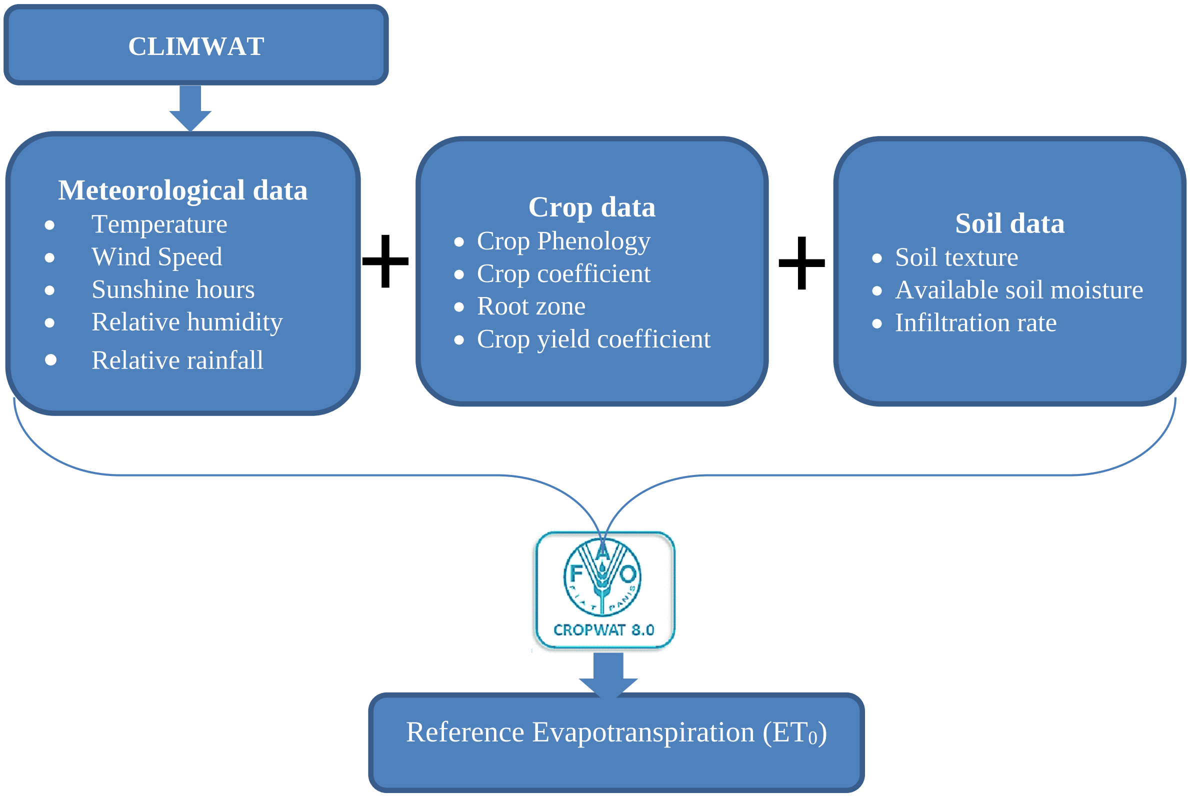

Figure *7*: Methodological framework for reference evapotranspiration estimation

3.2. Data required for estimation of the ET_0.

The following key parameters were retrieved from CLIMWAT and were used in CROPWAT for ET_0 estimation:

3.2.1. Temperature

It is necessary to obtain the daily maximum and minimum (average) air temperature in ET degrees Celsius (°C), If only the average daily temperatures are available, the calculations for evapotranspiration can still be done, but there is a possibility of underestimating ET_0 because the non-linear relationship of the saturation vapor pressure may not be fully specified for temperature relationship.

3.2.2. Relative Humidity

The primary factor that drives the vaporization of water is the energy received from the sun and the surrounding air. However, the difference between the water vapor pressure at the evapotranspiration surface and the surrounding air is the decisive factor for the removal of water vapor Fields that well-watered in hot and dry arid regions tend to consume significant amounts of water because of the plentiful energy available and the drying effect of the atmosphere. Conversely, in humid tropical regions, despite the high-energy input, the high humidity in the air reduces the demand for evapotranspiration. This is because the air in such an environment is already close to saturation, which means that less additional water can be stored and, as a result, the rate of evapotranspiration is lower than in arid regions (Allen et al., 1998).

3.2.3. Solar Radiation

The process of evapotranspiration relies on the availability of energy to convert water into vapor the primary energy source is solar radiation which has the ability to transform large quantities of liquid water into water vapor. The potential amount of solar radiation that can reach the evaporating surface depends on its geographical location and the time of year. The amount of radiation available varies across different latitudes and seasons due to the differences in the sun's position (Allen et al., 1998).

3.2.4. Wind speed

The average daily speed is measured in meters per second (m/s) at a height of 2 meters above the ground level. It is crucial to confirm the measurement height of wind speed because the speed may vary at different heights above the soil surface. Wind plays an important role in the process of evapotranspiration, which is the combined loss of water from the earth's surface through evaporation and transpiration from plants. The effectiveness of wind on evapotranspiration can be understood through its impact on the rate of water vapor diffusion and air movement around the plants. When wind speed increases, it can increase the rate of evaporation from the surface of soil and water, as well as increase the transpiration rate of plants (Allen et al., 1998).

3.3 Estimation of the Reference Evapotranspiration

The Cropwat model used in this study has been based on the Penman–Monteith Equation which estimates ET_0. The PM equation is given below:

1st Equation.

$$ET_0 = \frac{0.408\Delta(Rn - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad \text{Equation1}$$

where,

ET_0 = reference evapotranspiration (mm/day)

R_n = net radiation at the crop surface (MJ/m2/day),

G = soil heat flux density (MJ/m2/day),

T = mean daily air temperature at 2 m height (oC),

u_2=wind speed at 2 m height (m/s),

e_s=saturation vapor pressure (kPa),

e_a=actual vapor pressure (kPa),

Δ =slope vapor pressure curve (kPa/oC),

γ=psychrometric constant (kPa/oC).

e_s- e_a = saturation vapor pressure deficit (kPa)

2. RESULT

2.1. Reference Evapotranspiration (ET_0) across the Helmand River Basin

Figure 8 illustrate the estimated ET_0 (mm/month) in Ghazni Station is located on the highest elevation in the HRB. Figure 8 below shows the mean monthly ET_0 rate of Ghazni station. Likewise in the others graphs, June experienced the highest ET_0 which was 225 mm/month followed by August where mean ET_0 was 231 mm/month. Similarly, the least ET_0 was experienced in December and January which was 44 mm/month and 33 mm/month respectively. These are the months with the lowest temperature, which is one of the key drivers usually for ET estimation.

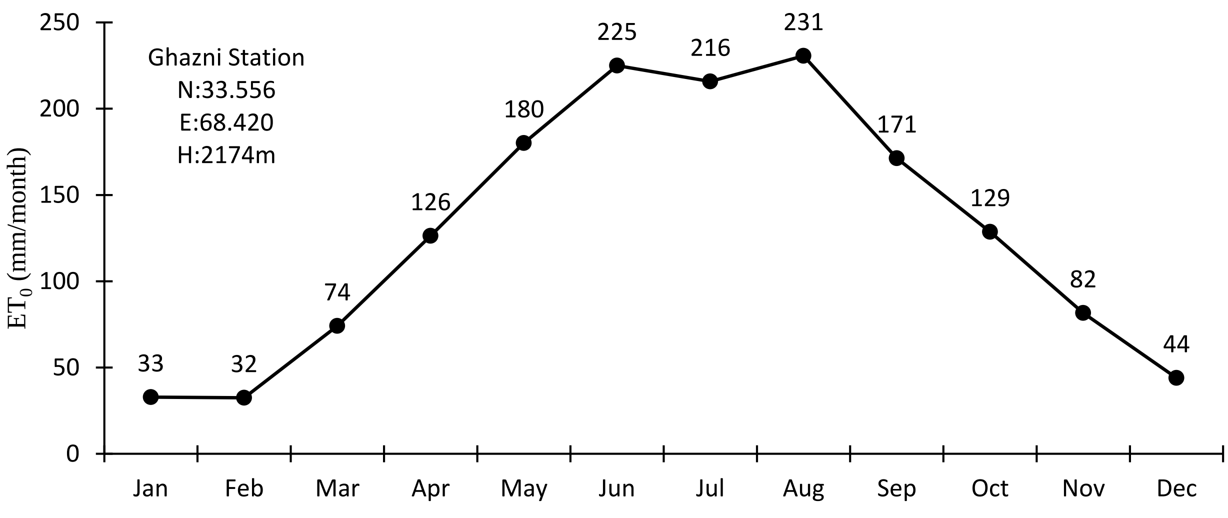

Figure 8: Monthly Value of Reference Evapotranspiration in Ghazni Station.

Figure 9 shows the mean monthly ET_0 , not very different from the other stations, Oruzgan also experienced the highest ET_0 during the months of June and July which was 227 mm/month and 234 mm/month respectively. Not different from other stations, December and January experienced the lowest ET_0 which was respectively 43 mm/month and 47 mm/month respectively.

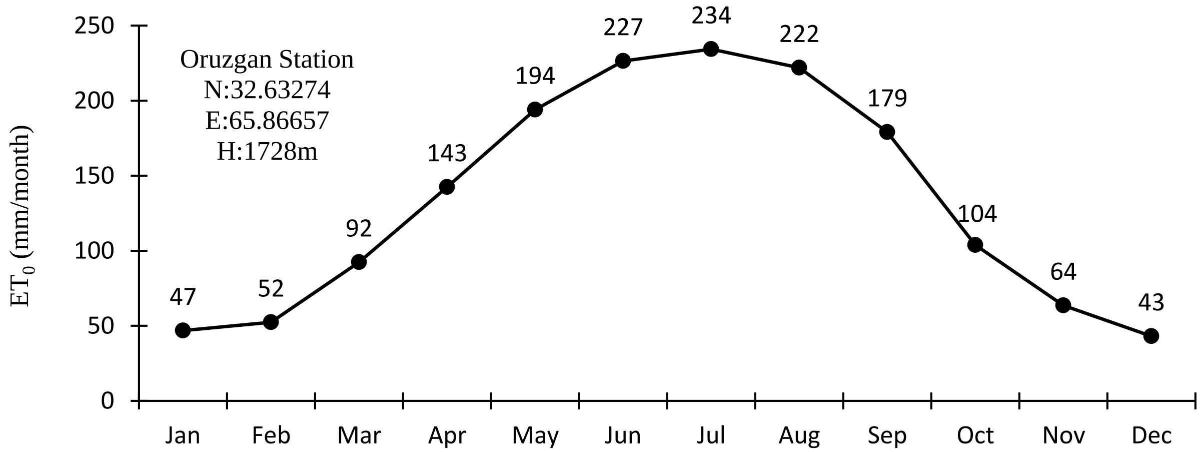

Figure 9: Monthly Value of Reference Evapotranspiration in Oruzgan Station.

The figure 10 illustrate that in Kandahar station the highest rate of ET_0 is in July experienced 282 mm/month. While As usual, the lowest ET_0 was experienced in the months of January and December (i.e. 70 mm/month) and (74 mm/month).

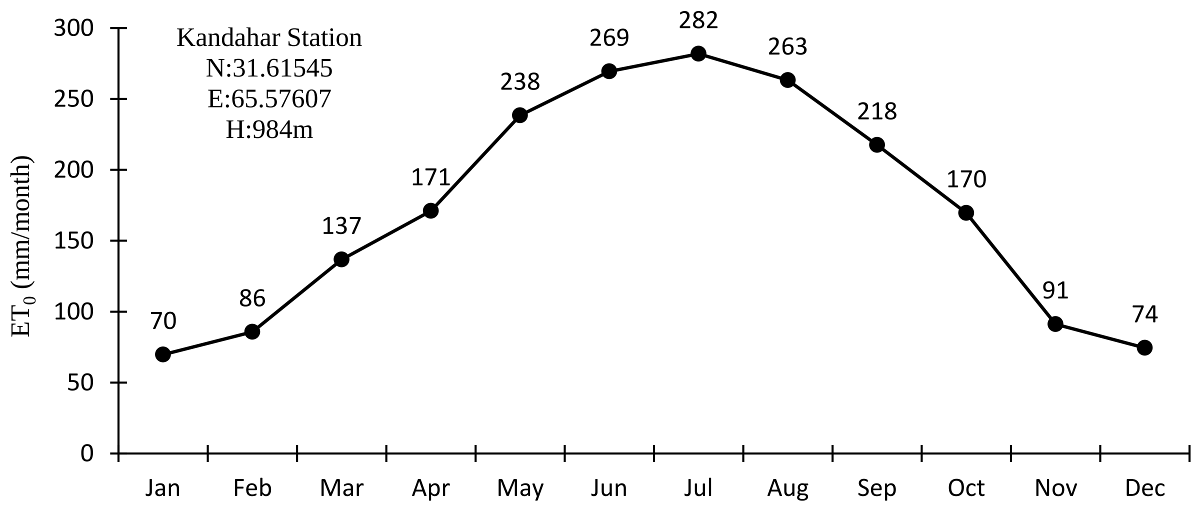

Figure 10: Monthly Value of Reference Evapotranspiration in Kandahar Station.

Below in figure 11, the mean monthly rate of ET_0 is given on Helmand station, which depicts that July experienced the highest ET_0 rate (240 mm/month). While the least ET_0 was experienced in the month of January which was around (65 mm/month).

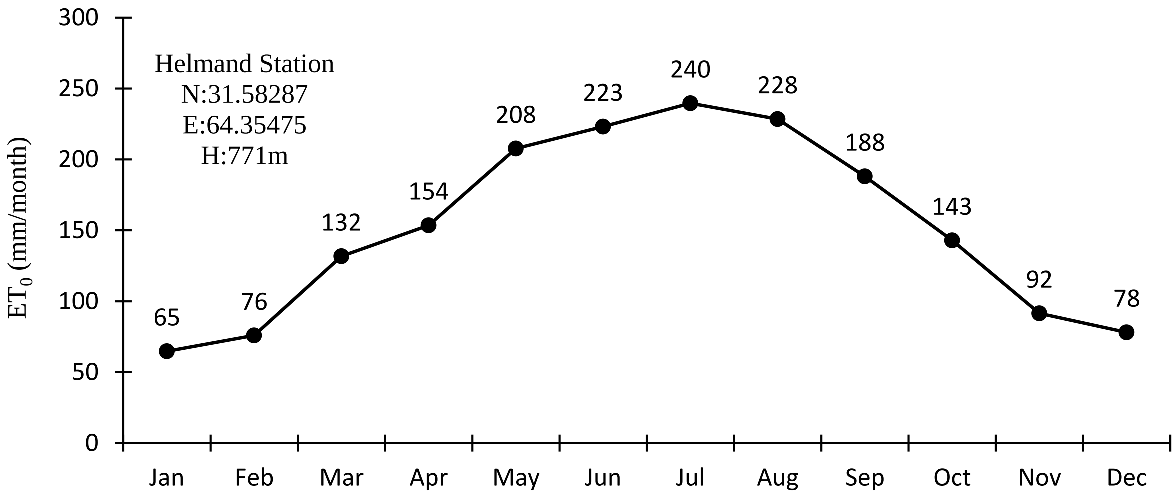

Figure 11: Monthly Value of Reference Evapotranspiration in Helmand Station.

Figure 12 shows that Farah experienced the highest mean annual ET_0 rate compared to other stations and is therefore, the most drought affected region among the western provinces. The highest ET_0 was experienced in the month of July which was 330 mm/month, and the least rate experienced in January (i.e. 61 mm/month) and December (i.e. 67 mm/month).

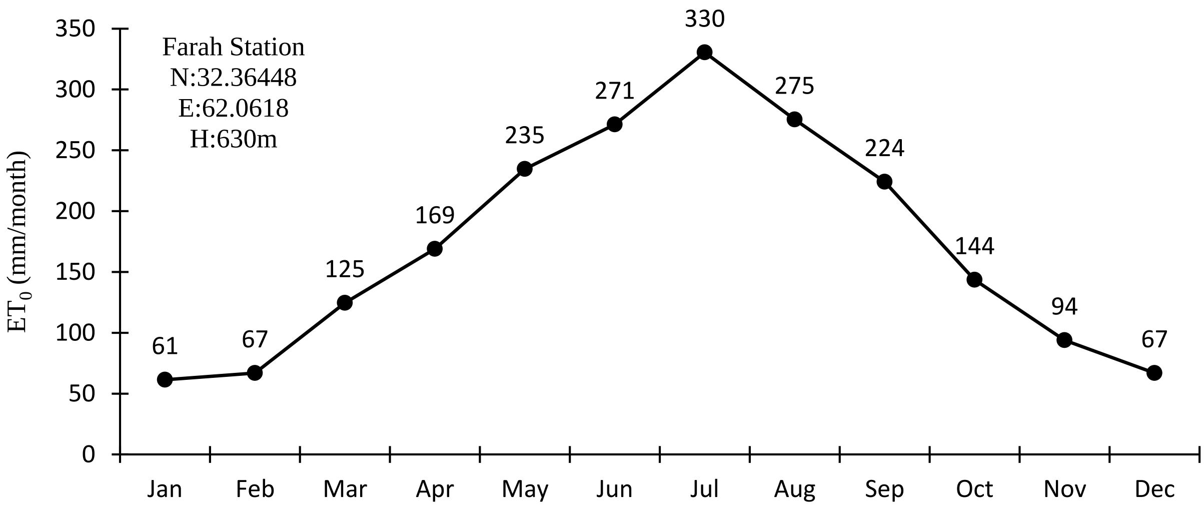

Figure 12: Monthly Value of Reference Evapotranspiration in Farah Station.

2.2. Summary of the Reference Evapotranspiration across the Helmand River Basin

The following table (Table 1) provides a detailed comparative analysis of the variation in ET_0 on monthly and annual basis

Table 1: Summary of the Reference Evapotranspiration across the different meteorological stations of the Helmand River Basin

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Ghazni	33	33	74	126	180	225	216	231	171	129	82	44	1543
Oruzgan	47	52	92	143	194	227	234	222	179	104	64	43	1601
Kandahar	70	86	137	171	238	269	282	263	218	170	91	74	2069
Helmand	65	76	132	154	208	223	240	229	188	143	92	78	1826
Farah	61	67	125	169	235	271	331	275	224	144	94	67	2062
Average	55	63	112	153	211	243	260	244	196	138	84	61	1820

3. DISCUSSION

According to Fischer and Van Velthuizen (2019), the mean annual ET_0 has been the highest in the HRB; historically, during 1961-1990, the mean annual ET_0 was around 1770 mm which increased to 1986 mm during 1981-2010. It is being projected within the same study that by 2050, the mean annual ET_0 is expected to increase up to 2018 mm and 2072 mm under the Representative Concentration Pathways of 4.5 and 8.5 respectively. Conversely, under our study, the mean annual ET_0 has been in the range of (1543 - 2069 mm/year) based on the date retrieved from the CLIMWAT. During 1961-2010, the mean annual actual evapotranspiration has been 146 mm (Fischer and Van Velthuizen, 2019), which is expected to decrease with increasing ET_0 rate and will, therefore, limit the water availability which will have dire consequences mainly for the agricultural sector.

4. CONCLUSION

Because of the impacts of climate change in Afghanistan, the HRB is specifically exposed to the multi-lateral issues. The anticipated increase in the ET_0 will limit the water resources availability for the biggest consuming sector, agriculture, and consequently will also limit the groundwater availability for the local population. Additionally, if the current agricultural cropping practices persist unchanged, in light of climate change projections indicating decreased annual precipitation, there will be significant adverse impacts on agricultural yield and biomass in the HRB region. Ultimately, this could lead to compromised food security as a consequence. It is, therefore, imperative to estimate these biophysical processes in order to develop water resources management plans thereby needed to mitigate the ill impacts of climate change. The use of state of the art models such as CLIMWAT and CROPWAT are helpful to identify the differences and increasing trend of the ET_0 rates under data-scarce conditions. This study provides valuable insights into the hydrological processes occurring within the HRB, as well as the spatiotemporal variations in ET_0 across the region.

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