Data Preparation for Assessing Impact of Climate Change on Groundwater Recharge

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Abstract— Climate change is a change in the statistical properties of the climate system when considered over long periods of time. It significantly affects the various components of hydrological cycle like temperature, precipitation, evapotranspiration and infiltration. All these components together affect the rate of groundwater recharge. So understanding the effects of climate change on groundwater recharge is the need of time for the management of groundwater resources. This paper presents the data preparation initiatives and a suitable methodology that can be used to characterize the effect of climate change on groundwater recharge. The method is based on the hydrologic model Visual HELP which can be used to estimate potential groundwater recharge at the regional scale. The success of Modeling depends on the accuracy of data and the mode of collecting the data. Therefore, identifying the data needs of a particular modeling study, collection/monitoring of required data and preparation of data set form an integral part of any groundwater modeling exercise. The main objective of this paper is to describe the exact data required and its preparation to simulate the groundwater recharge using HELP Model Software for Yavatmal as a study area situated in Maharashtra state, India. The impact of climate change as a pilot study is modeled by using computer software HELP (Hydrologic Evaluation of Landfill Performance). The initiatives for data preparation presented herein may be useful to the researchers in this field.

Keywords— Climate change, Groundwater recharge, Visual HELP

I. INTRODUCTION

We are living in a period of climate change brought about by increasing atmospheric concentrations of greenhouse gases. Global mean temperatures have risen 0.3–0.6 0C since the late 19th century and global sea levels have risen between 10 and 25 cm. It is also reported that the expected global rise in temperature over the next century would probably be greater than observed in the last 10,000 years. As a direct consequence of warmer temperatures, the hydrologic cycle will undergo significant impact with accompanying changes in the rates of precipitation and evaporation (Intergovernmental Panel on Climate Change, (IPCC), 1995).

Groundwater resources are related to climate change through the direct interaction with surface water resources, such as lakes and rivers, and indirectly through the recharge process. Therefore, quantifying the impact of climate change on groundwater resources requires not only reliable forecasting of changes in the major climatic variables, but also accurate estimation of groundwater recharge. Climate variability is affecting groundwater recharge and level due to changes in precipitation and evaporation loss. Domestic and agricultural water demand is sensitive to this variability in areas that rely to groundwater in many areas all over India. Central Ground Water Board (CGWB, 2007) reported that “Ground water has special significance for agricultural development in the State of Maharashtra. Ground water development in some parts of the State has reached a critical stage resulting in fluctuations of ground water levels. Thus, there is a need to adopt an integrated approach of development of ground water resources dovetailed with ground water augmentation to provide sustainability to ground water development”.

The collection of accurate data and preparing the data set for analysis is an essential part for modeling and forecasting the groundwater scenario for future due to adverse climatic change. Thus the paper prescribes the use of the groundwater recharge model called HELP (Hydrologic Evaluation of Landfill Performance) to study the effect of climate change on groundwater recharge. Further, the initiatives undertaken for accurate collection of data and preparation of data set for using HELP model are also described.

Study Area and its Features

The study area includes Yavatmal District. Its latitudinal extension is from 19º 26’ N to 20º 42’ N and its longitudinal extension is from 77º 18’ E to 79º 9’ E. The major portion of the district is a flat topped plateau with steep ghats having elevation of 550 m in NW side and 200 m in SE side from MSL. It is included in the SOI toposheets no. 56 M, I, E and 55 H, L. More detailed information related to study area is collected from Groundwater Survey and Development Agency (GSDA), Central Ground Water Board (CGWB), Dr. Panjabrao Deshmukh Agricultural University, Akola and Land Record office, Yavatmal and other regional offices.

II. LITERATURE REVIEW

Bokar H, et al. (2012)[1] carried out a collective work on "Impact of climate variability on groundwater resources in Kolondieba catchment basin, Sudanese climate zone in Mali" where high evaporation demand and short recharge period had led to groundwater level variability. Steady state groundwater flow modeling with the help of MODFLOW showed that groundwater is flowing into the river network while transient flow model showed a decline of water level during the time by an average groundwater drop varying from 2 to 15 cm per year in the period of 1940-2008. The results indicate that the model can be used to predict the groundwater level using downscaling values of the Climate Global Model data.

Mikko I. Jyrkama[2]**, et al. (2007)** presented a physically based methodology that can be used to characterize both the temporal and spatial effect of climate change on groundwater recharge. The method is based on the hydrologic model HELP3, can be used to estimate potential groundwater recharge at the regional scale with high spatial and temporal resolution. In their study, the method is used to simulate the past conditions, with 40 years of actual weather data, and future changes in the hydrologic cycle of the Grand River watershed. The impact of climate change is modeled by perturbing the model input parameters using predicted changes in the regions climate. The results of the study indicate that the overall rate of groundwater recharge is predicted to increase as a result of climate change.

Dr. Surjeet Singh and C.P.Kumar[3]**, (2011)** carried out research work on "Impact of Climate Change on Dynamic Groundwater System in a Drought Prone Area". The research dealt with the databases and their analysis, generation of future rainfall and temperature, recharge estimation and groundwater simulation for proper management and augmentation of groundwater in the basin. All the thematic maps were generated in ILWIS3.2 and necessary data were collected. Future rainfall was generated based on the SRES GCM projections for the South-Asia region for baseline, A1F1 and B1 scenarios for the time-slice 2004-2039. The site-specific soil, vegetation and climate database needed for the Visual HELP model was generated and site specific groundwater recharge was estimated at twelve locations in the basin. The groundwater simulation was obtained using the water balance method by dividing the whole basin into twelve zones. Finally, the quantification of impact of climate change on the groundwater recharge and levels for the time-slice 2004-2039 has done.

C.P.Kumar[4]**(2012)**assessed the impact of climate change on groundwater resources, recent research studies, and methodology to assess the impact of climate change on groundwater resources in context with soil moisture, groundwater recharge and resources and coastal aquifers. A brief review of research studies carried out in recent years has presented. Groundwater recharge estimation was carried out using WHI UnSat Suite and WetSpass. Climate data from weather stations was analyzed, modeled GCM and build future predicted climate change datasets with temperature, precipitation and solar radiation variables.

Allen D. M et al.[5]**(2003)** used the Grand Forks aquifer, located in south-central British Columbia, Canada as a case study area for modeling the sensitivity of an aquifer to changes in recharge and river stage consistent with projected climate-change scenarios for the region. This study attempted to estimate the recharge using Visual HELP within WHI UnSat Suite. Results suggested that variations in recharge to the aquifer under the different climate-change scenarios, modeled under steady-state conditions, have a much smaller impact on the groundwater system than changes in river-stage elevation of the Kettle and Granby Rivers, which flow through the valley. All simulations showed relatively small changes in the overall configuration of the water table and general direction of groundwater flow.

Schroeder P.R et al.[6](1994) gave background and overview of the model, and listed software and hardware requirements. It also described basic landfill design and liquids management concepts, definitions, options and limitations for input parameters as well as detailed guidance for selecting their input values. The detailed instructions on how to enter input, run the simulation and view or print output was also provided.

III. METHODOLOGY FOR ANALYSIS

The parameters required for climate change studies and other numerical methods can be estimated using such codes as HELP, UNSAT-H, SHAW, WEAP, and MIKE SHE. The 1D-program HYDRUS1D is available online. These codes generally use climate and soil data to arrive at a recharge estimate, and use Richards's equation in some form to model groundwater flow in the unsaturated zone.

As per many reported studies, the impact of climate change can be modeled by using computer software HELP (**H**ydrologic **E**valuation of **L**andfill **P**erformance) in which data such as rates of groundwater recharge, rate of evaporation etc. are difficult to quantify since other related processes such as evaporation, transpiration (or evapotranspiration) and infiltration processes must first be measured or estimated to determine the balance. It is possible to choose any study area as any part of country or worldwide for analysis purpose.

A. Visual HELP

The Visual HELP is based on water balance method. It can be used to calculate a groundwater recharge rate from precipitation (rain or snow, or both) under the influence of site-specific soil properties, solar radiation, air temperature, wind speed, and vegetative properties. The HELP model (Schroeder, et al., 1994) predicts an infiltration rate under quasi two-dimensional influences through one or more uniform soil layers. Application of the HELP model (Schroeder, et al.,

1994) has been done by contemporary groundwater practitioners to substantiate values of net recharge from precipitation obtained from historical studies for use in groundwater flow and contaminant transport models.

The Visual HELP model is used to calculate the potential net recharge to groundwater from precipitation under site-specific soil, vegetative and climatic conditions for a fictitious site near San Francisco, California, using the water balance method. The water balance method calculates potential net recharge as a residual of all other water balance components and is expressed as: R = P - D - ETa – DW

Where, R is potential net recharge, P is precipitation, D is net runoff, ETa is actual evapotranspiration, and DW is the change in soil water storage.

There are some limitations of water balance method. In arid and semi-arid regions application of the water balance method is more difficult to apply than in humid regions because precipitation in these regions is only slightly larger than evapotranspiration. Therefore, small measurement errors in either of these two components of the water balance equation can cause large errors in recharge rate estimates. Care should therefore be taken when applying the water balance method in water scarce regions, and should be used to calculate recharge events for one- to ten-day intervals to detect ephemeral recharge events common to the regions (Schroeder, et al., 1994).

The HELP program can generally be used to conduct simulations for very small and simple systems, where total number of different input parameters is small. However for large areas, the generation and analysis of HELP output files may become awkward resulting in considerable increase in pre and post processing times. Because the actual program uses simple input and output text files to define the simulation parameters and report the results (Mikko, et al., 2007).

IV. DATA COLLECTION AND DATA SET PREAPRATION INITIATIVES

Data collection for such study in an herculean task and then prepare that in the form of input to the software is the first major phase of groundwater modeling study. The data include all geological and hydrological information on surface and subsurface geology, water tables, precipitation, evapotranspiration, pumped abstractions, stream flows, soils, land use, vegetation, irrigation, aquifer characteristics and boundaries and groundwater quality. To develop a numerical model with help of any software, all the collected data must be converted into format suitable for working software. Thus the working on collected data to convert it into suitable format is called Data Preparation. It is the most challenging work and researchers have to tackle various difficulties. Hence the data can be gathered from many sources viz. National Bureau of soil survey and Land Use Planning (NBSS & LUP), Central Groundwater Board (CGWB), Groundwater Survey and Development Agency (GSDA), Agriculture University (AU), Internet searched papers and links and many other departments of geology, hydrogeology etc.

HELP requires various climatic, soil and design data to generate daily estimates of water movement though a soil column. The required input parameters for the model are shown in Table 1. Below enlisted paragraphs states parameters required, geological and hydrological data and various other data of Yavatmal District, Study area. Yavatmal District is considered as an example for preparation of data. Complete information and details along with figures gives clear idea for preparation of accurate data for input in HELP model Software.

A. *Geographical Information*

It is useful to locate the study area in the model. Latitude and Longitude of study area will give the exact location for study area. Survey of India Toposheets is also useful to prepare a map which shows the boundary of study area and spatial distribution of various parameters to be calculated in groundwater modeling. Maps are useful to locate the area wise water level fluctuation, Elevation, Hydrogeological parameters and many other parameters. It can be prepared using GIS based software Global Mapper. Fig 1 and 2 shows the exact location with elevation and Hydrogeology Map

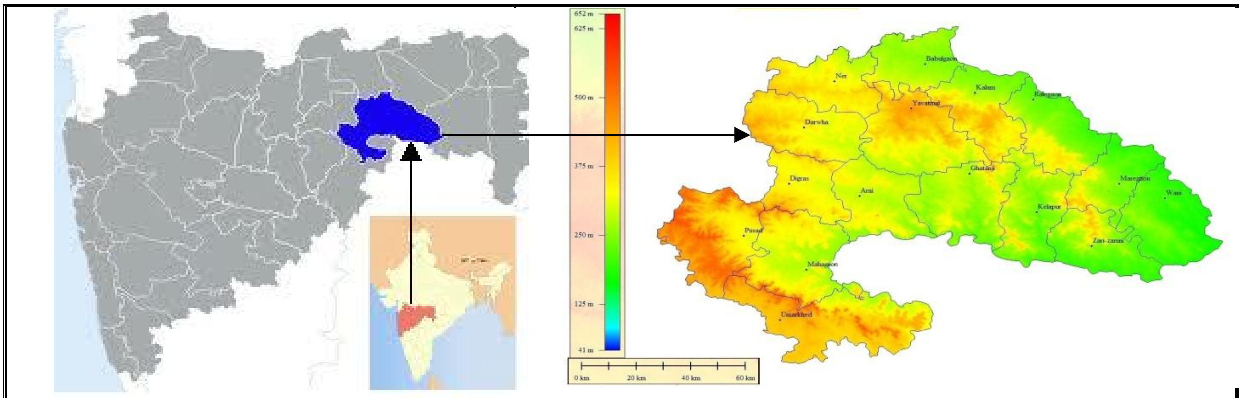


Fig. 1 Location and Elevation Details prepared in GIS based Global Mapper software

prepared using Global Mapper Software. These GIS based softwares are useful to compile all the information collected and resulting values for study area in the form of Map. These are the advanced techniques nowadays researches and many scientists are using because of accuracy and user friendliness. Fig. 3 is the map given by National Bureau of Soil Survey and Land Use Planning office Nagpur (NBSS&LUP).

B. ***Land use/ Land cover Data***

Land use and land cover (LULC) data for any region can be obtained from the District statistics department, Land use planning office or Agricultural research Centre situated in that District. These three offices can give the authentic data for land use and land cover information for the study area region. The Digital Map for Land use can also be generated using GIS based software like Arc GIS, Global Mapper and all other. Land use Maps are readily available in National Bureau of Soil Survey and Land Use Planning department situated at Nagpur. Groundwater modeling in HELP needs to formulate runoff curve number which depends on land use and land cover at study area. The LULC also useful to determine the values of vegetative parameters like Leaf area index, Evaporative zone depth.

C. ***Soil Data***

The surface soil information can be assembled from various regional soil surveys conducted in that area by the Soil survey offices. The most accurate and reliable data related to soil survey can be obtained from National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) office. This office is aimed to conduct soil survey and mapping of the soils of the country at various scales to promote scientific and optimal land use programs in collaboration with relevant institutions and agencies and proper documentation of database. NBSS & LUP office is able to provide the plant available water which is the water content difference between field capacity and permanent wilting point of soil at given depth. Plant available water is easy to calculate but accurate estimation of both field capacity and permanent wilting point are necessary for the value to be helpful in irrigation scheduling. These data can also be available with Irrigation Department or Agricultural Research Centre in District office or Agricultural universities.

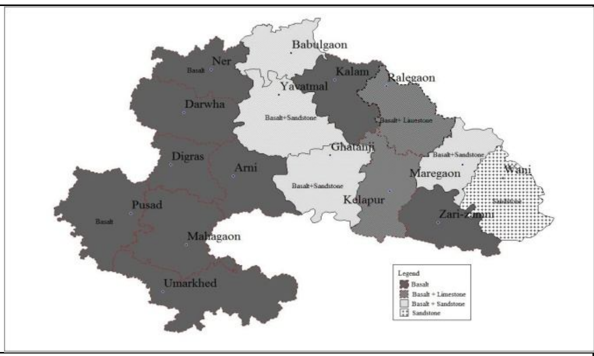


Fig.2 Hydrogeology of Yavatmal

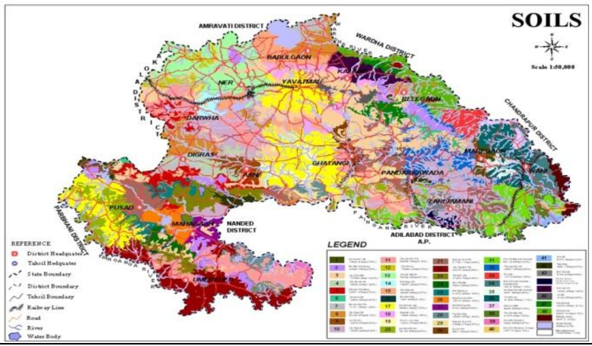
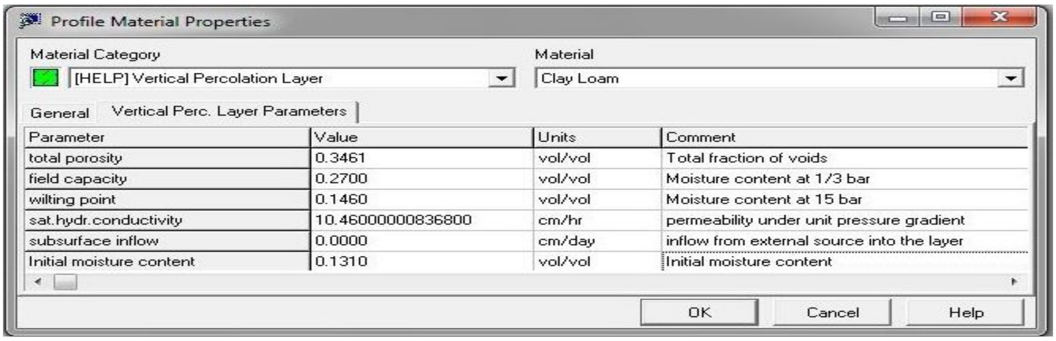


Fig. 3 Soils in Yavatmal (courtesy : NBSS)

Field capacity is the water content of the soil two to three days after a rain or irrigation event when the remainder of water has been removed by the downward forces of gravity. This value of field capacity assumes that the water removed from the soil profile is only removed by gravity, not through the plants or through evaporation. Because of this, field capacity estimates are generally done before the growing season. In the USA and some other countries, the soil is considered to be at field capacity when the water potential in the soil is at -33 kPa. Field capacity is not the same as saturation. When the soil is saturated, all the spaces between the soil particles are filled with water. When the soil is at field capacity, the spaces between the soil particles contain both air and water. The structure and texture, of the soil determines how much water can be held in the soil. Sand, for example, does not hold a lot of water because the large grains do not have a lot of surface area Therefore, its field capacity, or the amount of water in the soil remaining after a large irrigation event, can be as low as 10%. Clay particles, on the other hand, are often shaped like upside-down dinner plates randomly stacked on top of one another with large amounts of surface area. The large surface area and structure of clay soils can have a field capacity above 40%.

The permanent wilting occurs when the volumetric water content is too low for the plant to remove water from the soil. About half of the water in the soil at field capacity is held too tightly to be accessible to plants. The soil is considered to be at permanent wilting point when the water potential in the soil is at or below -1.5 MPa, so the permanent wilting point is the water content of the soil at -1.5 MPa water potential. Soil at permanent wilting point is not dry. When the water content of a soil is below the permanent wilting point, water is still being present in the soil, but plants are unable to access it.

However, several difficulties we may have to encounter during the sampling and testing the soil samples in soil survey laboratory. HELP software requires physical and chemical details which also includes soil type, number of layers, layer depths, and soil texture classification. By using this subsurface data HELP model itself will combine with surface cover information to estimate the SCS curve numbers. Fig. 5 shows the soil layer properties used in Visual HELP software as input.



Profile Material Properties

Material Category: [HELP] Vertical Percolation Layer — Material: Clay Loam

General | Vertical Perc. Layer Parameters

Parameter	Value	Units	Comment
total porosity	0.3461	vol/vol	Total fraction of voids
field capacity	0.2700	vol/vol	Moisture content at 1/3 bar
wilting point	0.1460	vol/vol	Moisture content at 15 bar
sat.hydr.conductivity	10.46000000836800	cm/hr	permeability under unit pressure gradient
subsurface inflow	0.0000	cm/day	inflow from external source into the layer
Initial moisture content	0.1310	vol/vol	Initial moisture content

OK Cancel Help

Fig. 5 Soil Layer Material Properties

D. ***Weather Data***

The HELP model requires meteorological data that must be provided as daily values of Precipitation, Mean air temperature. As per the definition of climate change i.e. Climate change is a change in the statistical properties of the climate system when considered over long periods of time; Therefore actual daily precipitation and temperature records from previous 40 years or more than that (if available)are useful in the climate change study. This data are available in Regional departments of Indian meteorological departments (IMD). More site specific data will give the more accurate results. HELP will then uses this data to, (a) Calculate the volume of water flowing into the landfill, and simulate surface runoff, evaporation, vegetation growth and transpiration, and infiltration during warm periods; and (b) Simulate surface storage, snowmelt, runoff and infiltration during cold periods.

For synthetic generation of daily values of precipitation, mean temperature, and solar radiation DOS HELP and Visual HELP version 1 included a Weather Generator developed by the Agricultural Research Service of the USDA (U.S. Department of Agriculture), as well as parameters for generating synthetic data for 139 U.S. cities. After Visual HELP 1.01 was released, WHI received requests from clients worldwide to expand the area of Weather Generator application to other regions of the world trying to meet these requests, WHI developed a global database that includes more than 3000stations and a GIS feature for searching the nearest stations globally for the Visual HELP version 2.1. If landfill site is not located in database, it is recommend choosing the closest city to site and using the generated data for that location for simulations. Visual HELP will search for the closest location of a given set of co-ordinates. This co-ordinate set can be entered as actual values or interactively with a map. To import weather data not found in the database, it must be modify the format of data so that it meets the standards of Visual HELP. If the site is in Canada, you can automatically import data in the format of the Canadian Climate Centre. Customers in the U.S.A. may automatically import data in the NOAA format. Visual HELP checks NOAA files for missing daily and monthly record sand informs the user about the times, for which data are missing to make the correction process easy. To convert the daily weather data in Visual HELP format researcher have to work out for the statistical parameters given in Table 1. After this input HELP will

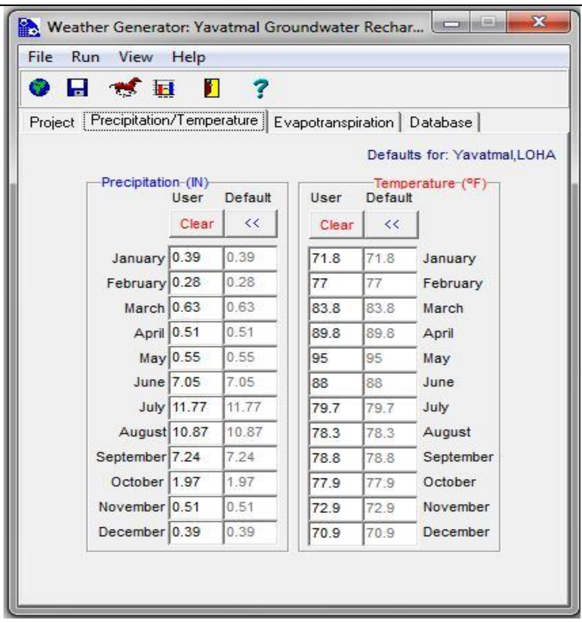


Fig. 5 Mean Monthly Temperature and rainfall

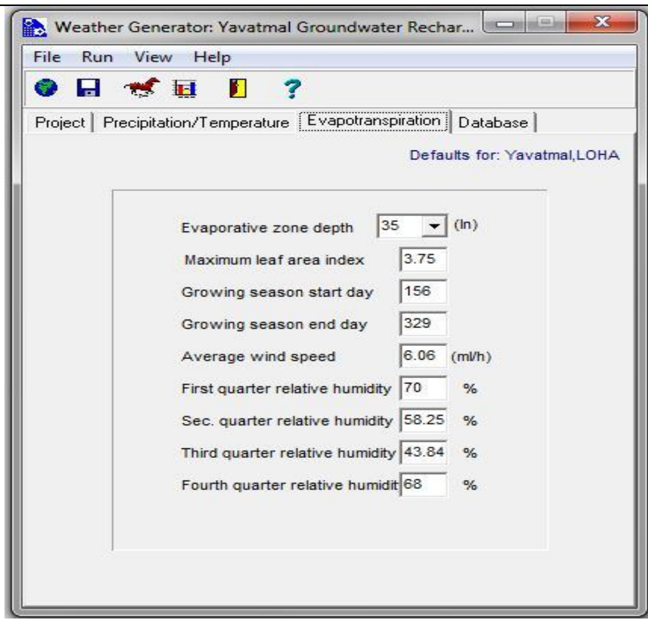


Fig. 6 Evapotranspiration Data

results the graph which shows the climate changing scenario for given 41 years time period as shown in Fig 8 and 9 for study area.

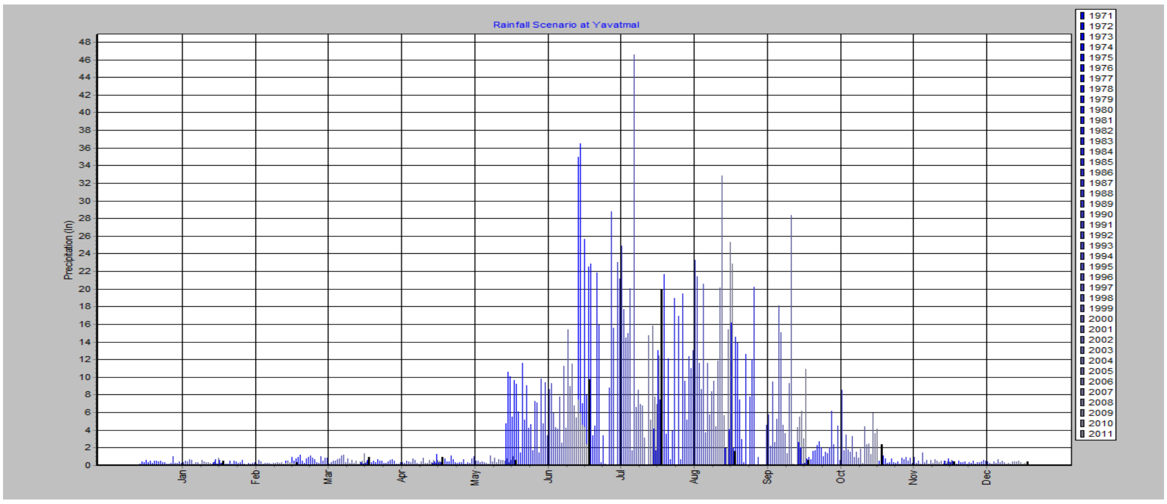


Fig .8 Daily Rainfall Pattern at Yavatmal

E. ***Vegetation Data***

Plant roots can have a significant impact on recharge as they remove infiltrated water from the soil. However, the determination of plant root penetration and subsequently the evaporative zone depth in model (i.e. the Maximum depth from which water may be removed by evapotranspiration) are very difficult tasks. HELP also requires a value for the maximum leaf area index (LAI) to calculate transpiration rates for the vegetative cover. Following the guidelines in HELP, where the LAI ranges from 0 for bare ground to 5.0 for Maximum leaf coverage, the values for LAI can be assigned based on the LULC data. For the study the relevant information outputs are as follows:

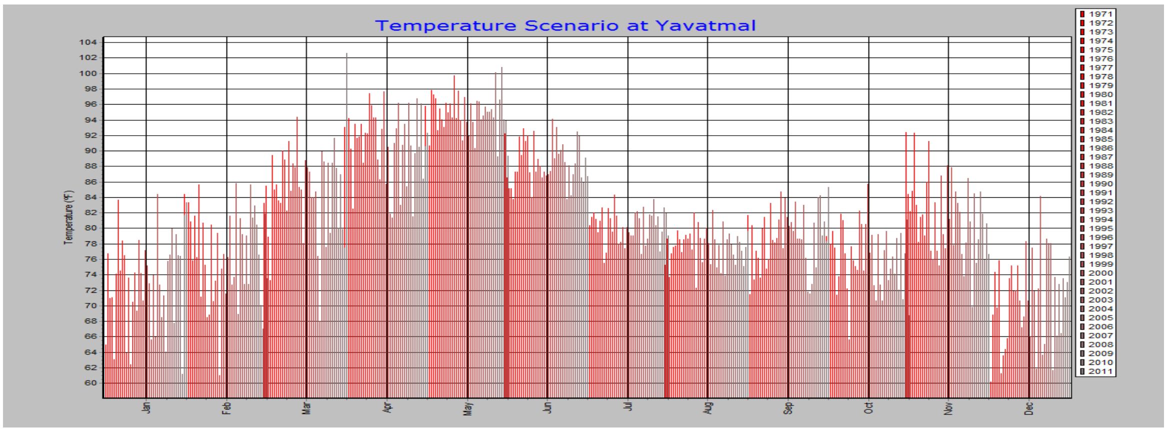


Fig. 9 Daily Temperature at Yavatmal

Sr. No.	Parameter	Units
1	Daily Precipitation	mm/day
2	Daily Mean Temperature	^{0}C
3	Relative Humidity (Two Quarter)	%
4	Growing Season start Day	
5	Growing season end Day	
6	Evaporative Zone Depth	Cm
7	Leaf Area Index	-
8	Soil Layer Depth (Each Layer)	Cm
9	Soil Texture (Each Layer)	-
10	Total Porosity (Each Layer)	Vol/vol
11	Field Capacity (Each Layer)	Vol/vol
12	Wilting Point (Each Layer)	Vol/vol
13	Hydraulic Conductivity (Each Layer)	Cm/sec

Table 1 Summary of Input data required to be collected for HELP model

Table 2 Summary of input data prepared for HELP Software

SrNo	Parameter	Unit/ Values
1	Latitude of weather station	20°23'25"
2	Longitude of weather station	78°05'20"
3	Mean Maximum Temperature for Dry periods	117.9°F
4	Mean Maximum Temperature for wet periods	94.84°F
5	Mean Minimum Temperature wet and dry	70.9°F
6	Maximum Leaf Area Index	3.75
7	Evaporative zone Depth	35.43 In
8	Mean Annual Wind Speed	9.75 Kmph
9	Mean Relative humidity (Morning)	58.25%
10	Mean Relative humidity (Evening)	43.84%

HELP program can generally be used to conduct simulations for very small and simple systems, where total number of different input parameters is small. However for large areas, the generation and analysis of HELP output files may become awkward resulting in considerable increase in pre and post processing times. Because the actual program uses simple input and output text files to define the simulation parameters and report the results (Mikko, et al., 2007).

V. CONCLUSIONS

Data collection and preparation is an important task to be completed during simulation of any groundwater related study. The very first task is to collect groundwater level data for district, from Groundwater Survey and Development agency (GSDA) and find out the most influencing region to estimate the response of groundwater recharge to potential climate change. As demonstrated in this paper it is suggested that the Visual HELP is an excellent tool for such studies as compared to other Hydrologic models, because it can be easily applied to heterogeneous soil columns with physically based boundary conditions to quantify in detail the influence of climate change. Daily rainfall and temperature is recommended to collect from authenticate regional Meteorological centre. It is required to carry out statistical analysis of daily weather data and then put up in software. In Fig 1, 2, 3 shows the Maps which were prepared using GIS based Global Mapper software by compiling all the geographical data collected from regional agencies, further snapshots of HELP software shows the prepared input data in Fig. 4, 5, 6. The input parameters of HELP software mentioned in Table 1 and 2 indicate the data collected and prepared accordingly. With this preparation now it is possible to launch the pilot study on impact of climate on groundwater recharge. It is also felt that discussion with the scientists and field officers in various offices like CGWB, NBSS, National Institute of Hydrology, Indian Meteorological Department, will be useful to give the correct path and direction for collection and preparation of Data. For better understanding an example of Yavatmal district is also stated showing all clear direction how to collect and prepare the data for input in software. The initiatives presented herein may be useful to the researchers in this field.

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