# On the Development of Climate Data Visualization tool for Interpretation of Empirical Results from Climate Model: Does it add Value to Different Stakeholders?

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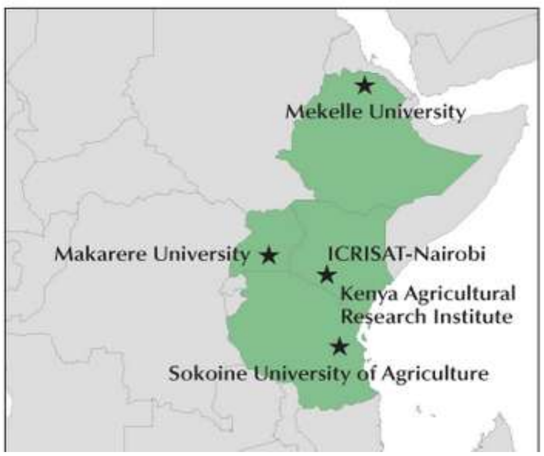
## Abstract

In time of climate change there is a lot of interest in communicating detailed information and knowledge pertaining to climate to different stakeholders. In order to aid informed decision making related to changing climate and weather variability there is need for data visualization tool. Data visualization tool plays a great role in interpreting bulk climate information produced or collected from different districts, regions and nations at large. In Tanzania, online real-time data visualization tool can help to bridge the gap in the current system whereby climate information is disseminated using television, radio as well as face-to face. These methods have many problems, one being difficulty for end user to aggregate the disseminated climate information over long period of time. This paper seeks to present a work toward developing of a tool for such purpose. The work was done by Database for Crop Models Simulation team from Tanzania with consultation of team members from Kenya, Uganda and Ethiopia. It is anticipated that the tool will enhance efficiency and effectiveness in dissemination and communication of climate information and knowledge to all actors who need it. Furthermore, the results from this study will simulate the debate about climate data visualization in this era where the climate change is a problem which needs to be mitigated using a state-of-art solution.

**Keywords:** climate, modelling, information, knowledge, dissemination, communication, visualization tool

## 1. Introduction

Recently there have been many researches done to address the effect of climate change (WAISSWA, OTIM & Milton, 2012; Kaye, Hartley, & Hemming, 2012; Neset et al., 2009; Nocke et al., 2008). These efforts have been done by different researchers in different area of specialization. These include climatology, computer science, computer engineering, social science, chemists, physicists etc. Evaluating the effect of climate change without integrating with other different disciplines is a major weakness of many previous studies (Weyant et al., 1996; Rosenzweig et al., 2012a; Rosenzweig et al., 2012b). It is from this that Agricultural Model Inter-comparison and Improvement Project (AgMIP) want to fill the gap in knowledge. AgMIP is a major international effort linking the climate, crop, and economic modeling communities with cutting-edge information technology to produce improved crop and economic models and the next generation of climate impact projections for the agricultural sector. The project "Assessing the impacts of climate variability and change on agricultural systems in Eastern Africa while enhancing the region's capacity to undertake integrated assessment of vulnerabilities to future changes in climate" is one of the projects selected for conducting these assessments in four East African countries-Ethiopia, Kenya, Tanzania and Uganda and is funded by AgMIP through the support from UKaid (http://www.agmip.org/).




Map 1: Team Composition for East Africa AgMIP (Adopted from www.agmip.org)

One of the approaches used in AgMIP project is to use the existing data collected by different researchers in climate, crop and socio- economic to predict different future scenarios under effect of climate change. The challenge for these collected data is how to simplify data visualization in order to establish certain patterns in order to answer different research questions. Even though this paper presents a tool for data visualization for general purpose system we shall present with reference to climate data.

Data visualization is the field dealing with visual representation of abstract data into more clear graphical way (Nocke et al., 2008). The presentation in a graphical must be able to communicate the information easily and effectively to the user. Since simulating models result into many outputs files consisting of spatial and complex data, there is need of a tool for visualizing easily (Johansson et al., 2010). The aim is to convey the information and if possible, the knowledge to be extracted from the outputs files (which are in form of AgMIP data format) in a presentable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and readable manner to the end user. This paper contributes on the problem of user centered design as outline by Chen (2004) in his paper 10 unsolved problems in information visualization.

Tool for visualization of climate data has been developed purposively for scientists and professionals in climate and weather in many years but in recently, there is need for interpretation of climate results from simulated and modeled data to be used by different stakeholders (Otim and Waisswa, 2012; Pettit et al., 2012). The reasons for increased availability of tools for visualization of data related to climate are (i) advancement of ICT with resulted into lowering cost for computing devices (IPCC, 2007). (ii) the need to assess climate in relation to other areas of science (for example socio-economic, crop and IT) (Rosenzweig et al., 2012a) (iii) the computer methods, techniques and algorithms for developing interactivity for data visualization tools have increased substantially (Neset et al., 2009). The increased number of visualization tools has in turn resulted into large simulation data sets from climate, crop and socio-economic modelers (Nocke, Sterzel, Böttinger, M., and Wrobel, 2008). However the simulated data sets resulted from simulation need to be communicated to different stakeholders that is why visualization tools are developed to serve this purpose. Climate visualization tool are difficult to develop because of: (i) heterogeneous of climate data (ii) heterogeneous of climate stakeholders (iii) multi-disciplinarily nature of the experts needed to partner in looking for either general or specific purpose visualization system (Nocke et al., 2008; Ladstädter et al., 2010; Fuchs, & Hauser, 2009; Edelson, Gordin,1998; Shaw, Sheppard, Burch, Flanders, Wiek, Carmichael, & Cohen, 2009; Wei, Santhana-Vannan & Cook, 2009). Besides the above challenges, climate data centres face problems in achieving, managing and distribution of data in open access model (Wei, Santhana-Vannan & Cook, 2009). This facilitates data sharing and interoperability across network, organizational, and geopolitical boundaries.

Even though tools for climate visualization is at maturity stage but in developing countries there are few such tools to be used as (i) communication (ii) decision support (iii) analytical purposes to different stakeholders (Schneider, 2012). The climate visualization tool is of great importance in decision support, analytical and communicating the climate knowledge after the climate data has been modeled using climate models (Nocke et al., 2008). The good example of climate visualization tool is the web based climate visualization tool developed by University of the Cape Town (http://cip.csag.uct.ac.za/webclient2/app/). The problem of this type of general purpose visualization tool is that it is not dynamic to accommodate any user inputs and thus, does not allow any user to enter and analyse data. This is the weakness which has been identified by Nocke et al., 2008 who argue it lacks support for some of the typical domain specific requirements such as support for native file formats, and metadata, different grid types and mapping. Another weakness is that it is difficult for end user to interactively visualize different scenarios from general climate data sets after being modelled by climate models (Ladstädter et al., 2010). It is from this that necessitated the need for localized and contextualized solution for an integrated modeling from socio-economic, crop and climate. This is the goal of IT group for AgMIP in Tanzania. Thus, we aimed at developing a flexible visualization tool which will help climate team and other actors in climate and weather value chain to make informed decision from the current and predicted future scenarios. In this paper, the weather data series for simulated climate data for 30 years from 1980 to 2010 have been used.

## 2. Research methodology

The study involved an action oriented research (Sanga et al., 2013). The objectives for this research work was achieved by first doing literature review. As proposed by Keim et al (2008) and Keim (2002), the research methods in this visualization study also integrated other methods from scientific analytics, geospatial analytics, interaction as well as cognitive and perceptual science, visual analytics, statistical analytics, knowledge discovery, data management as well as knowledge representation and presentation, production and dissemination and information analytics. Literature review was undertaken in related work on web-based solutions for data visualizations in the field of climate and related other domains (Nocke et al., 2008; Ladstädter et al., 2010; Fuchs, & Hauser, 2009; Edelson, Gordin,1998; Shaw, Sheppard, Burch, Flanders, Wiek, Carmichael, & Cohen, 2009; Wei, Santhana-Vannan & Cook, 2009).

The focus was on the techniques used and weaknesses of existing solutions in visualization of climate data. Based on the findings in the literature review, a web- based visualization tool was developed following iterative incremental software engineering methodology (Larman and Basili, 2003). Requirements were collected from Tanzania Meteorology Agency (TMA), and then the requirements were divided into several iterations on priority bases starting with those having high priority. Thereafter, the mixed research approach was used; the approach has the capacity to capturing both qualitative and quantitative data in instances where there is missing climate data in the collected dataset. Specifically; focus group discussion, interviews, document analysis, surveys and observations was used in collecting data from intended population. The collected data was analyzed and its results were used as input for the architectural design. The architectural design of the software was done followed by design of each software component in each of the iterations. Software components was developed and tested followed by testing of the entire system. Testing of the software with different stakeholders (e.g. different line ministries (agriculture, environment, water, policy/planning, local governments, Academia), Climate change center / focal persons), Representatives of farmer associations Intermediaries: Government and non-governmental developmental agencies, Media) to obtain user feedback was also be done. Based on the feedback, improvements were done before releasing the final product. Thus, the potential benefits of the adopted action oriented research were realized; which is its power to assess the practical differences attained by the intended population. Coincidental the adopted research approach inherently adopted some features of the Living lab methodology (Buitendag et al., 2012) in an empirical experiment (Sanga, 2010).

## 3. Research design

This study employed a participatory action research (PAR), which was developed together with the AgMIP Tanzania group. Before being used, it was validated in a number of workshops attended by AgMIP Tanzania group members in Oasis and Nashera, Morogoro. Thereafter, it was pre-tested in computer laboratory. Subsequently, it was presented in AgMIP workshop done in Nairobi – Kenya and Adama – Ethiopia in 2012 and 2013.



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Table 1: How PAR was used in this study (Adapted from Sanga et al., 2013)

| Phase | Specific Activities |
|---|---|
| Diagnosing | • Semi-structured interviews with researchers,<br>• Use of checklists by inspecting data available in national agricultural research centres<br>• Assessing available literature review and climate data from TMA |
| Action planning | • inception workshop in Enttebe, Uganda<br>• several writeshop in Tanzania, Ethiopia, Kenya |
| Action taking | • developing climate data visualization tool using prototype approach<br>  • climate data visualization tool analysis and design<br>  • climate data visualization tool implementation<br>  • climate data visualization tool evaluation |
| Evaluation | • climate data visualization tool demonstration to different researchers in workshop<br>• Group Discussions with different researchers from Kenya, Uganda, Ethiopia and Tanzania to get their feedback |
| Specifying learning | • Presentations in conference |

## 4. Area of Study

The simulated data which was used in this paper were collected from different weather stations. It consisted of weather data for 30 years from 1980 to 2010 for Dar es Salaam airport, Dodoma airport, Mtwara airport, Musoma MET, Same MET, Tanga airport, Mbeya MET, Mahenge MET, Kisarawe Agriculture, Lindi Agriculture and Bukoba MET weather stations.

## 5. Study population

Study population is a finite or infinite collection of items or people under consideration (Kothari, 2007). The population for this study comprised of weather data for eleven weather stations.

## 6. Sampling Procedure

Purposively sampling design was used to obtain the study sample in which 11 weather stations from different agro-zone climatic conditions were selected. Another factor for selecting the weather station was the easy at which its weather data can be obtained without hurdles. Additional criteria was the limited budget and time thus, the existing data present from previous projects were preferred in comparison to collecting new data from the fields.



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## 7. Data collection

The data which was used for this experiment was collected from TMA.

## 8. Data analysis

Data which was collected from TMA subjected into Climate modeling software. Thereafter the output from climate model was taken as input for our experiment.

It is worth to note that all the research processes and outputs were communicated to researchers with the help of discussion group (agmip_tanzania agmip_tanzania@googlegroups.com; AgMIP EasternAfrica <agmipeastafrica@gmail.com>), facebook page (https://www.facebook.com/ECCAAW), blogs (http://agmipeastafrica.blogspot.com/ & http://agmipeasternafrica.wordpress.com/).

## 9. Results and discussion

The living lab and PAR methodologies resulted into the formulation of the framework for the database implementation and data visualization.

From the framework in Figure 2, we developed a prototype system for data visualization. It works for either field data or output data (from different models) in AgMIP format. The example of modelled climate data which has been used in this paper came from different weather stations in Tanzania and it has the data format as depicted below (Figure 1). Since the aim was to visualize climate data series from areas where modelling and simulation of the selected crop and socio-economic was being done, the collected data series were having many fields apart from those relating to weather. In simulating crop and socio- economic data sets, the weather data sets in the respective area was used. Due to the confidentiality of some weather data, bcMERRA dataset were used. A protocol set by AgMIP was that a local station climate series is preferred, but if it cannot be made public then it must be compared to bcMERRA dataset (Rosenzweig et al., 2012b).

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File  Edit  Format  View  Help
*WEATHER DATA : BUKOBA MET. STATION, Tanzania from bcMERRA output
@ INSI LAT LONG ELEV TAV AMP REFHT WNDHT
NLHA 51.967 5.633 7.0 -99.0 -99.0 1.5 2.0
@DATE YYYY MM DD SRAD TMAX TMIN RAIN WIND DEWP VPRS RHUM
1980001 1980 1 1 2.5 1.4 -1.2 6.2 3.5 0.2 6.2 92
1980002 1980 1 2 3.5 1.4 -6.5 0.0 1.7 -1.9 5.3 78
1980003 1980 1 3 1.5 0.1 -8.2 0.2 2.2 -3.0 4.9 80
1980004 1980 1 4 0.7 3.5 -0.3 3.0 4.5 1.1 6.6 84
1980001 1980 1 1 2.5 1.4 -1.2 4.2 3.5 0.2 6.2 92
1980002 1980 1 2 3.5 1.4 -6.5 15.4 1.7 -1.9 5.3 78
1980003 1980 1 3 1.5 0.1 -8.2 7.2 2.2 -3.0 4.9 80
1980004 1980 1 4 0.7 3.5 -0.3 7.5 4.5 1.1 6.6 84
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Figure 1: AgMIP Data format for Bukoba MET Station



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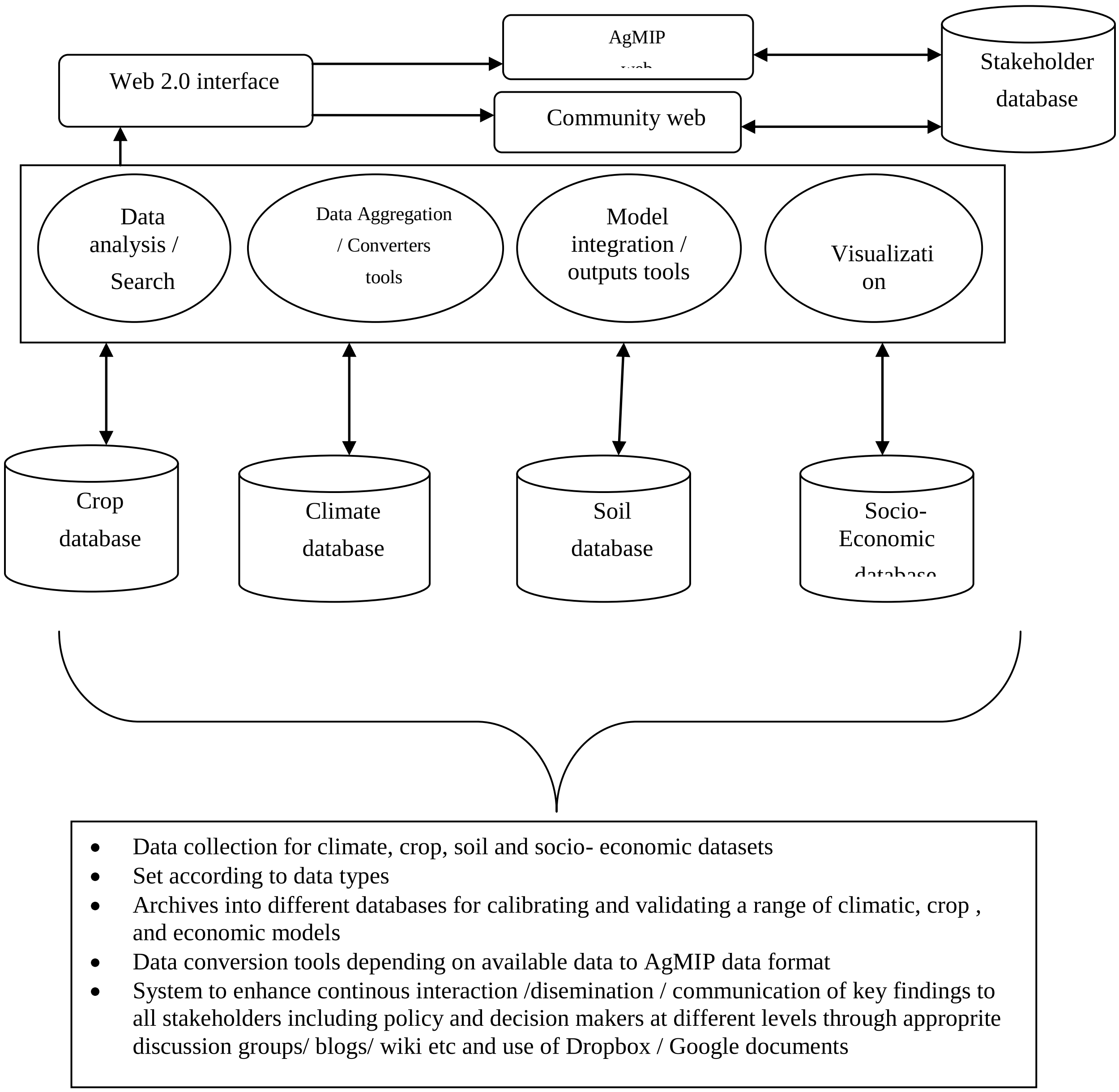


Figure 2: Framework for developing prototype of climate data visualization tool

## 10.Data Extraction, Transformation and Loading (ETL) Process

The data can be into different file formats but the challenge was how linking can be done without losing their original format (Wei, Santhana-Vannan, & Cook, 2009). This led the system analyst to use the techniques of data warehouse in designing the data visualization tool. The reason behind this was that there were voluminous quantities of weather data which need to be cleaned, filtered, extracted, transformed and loaded into a knowledge engine ready for mining, searching and reporting (Fayyad et al., 1996). This process helped data fusion from different data sources and data formats (e.g. excel, database, flat files) stored for 30 years


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starting from 1980 to 2010.

After the above data has been linked for visualization using AgMIP weather File Reader it shows visualization results which is obtained after specifying the range of date which one need to get the graph, AgMIP data from the station and type of the graph (Figure 3). The type of graph can be for solar radiation, maximum temperature, minimum temperature, precipitation (rainfall), wind speed, dew point temperature, vapour pressure and relative humidity in a period of 30 years. Since it is difficult to plot the graph for each for the data sets for the entire 30 years then the maximum, mean and average was used. These statistic variables were meant for showing realistic, optimistic and pessimistic respectively.

In order to achieve an expressive and simple way of representing large data related to climate in a varying timeframe there is a need of choosing a better way of visualization (Aigner, Miksch, Muller, Schumann, & Tominski, 2008; Li, & Kraak, 2012). According to Aigner et al (2008) there are three methods visualizing large climate data namely: temporal data abstraction, principal component analysis, and clustering of larger volumes of time-oriented data.

Figure 1: AgMIP - Weather File Reader

The following Figure shows output after the “Show Info” has been clicked.



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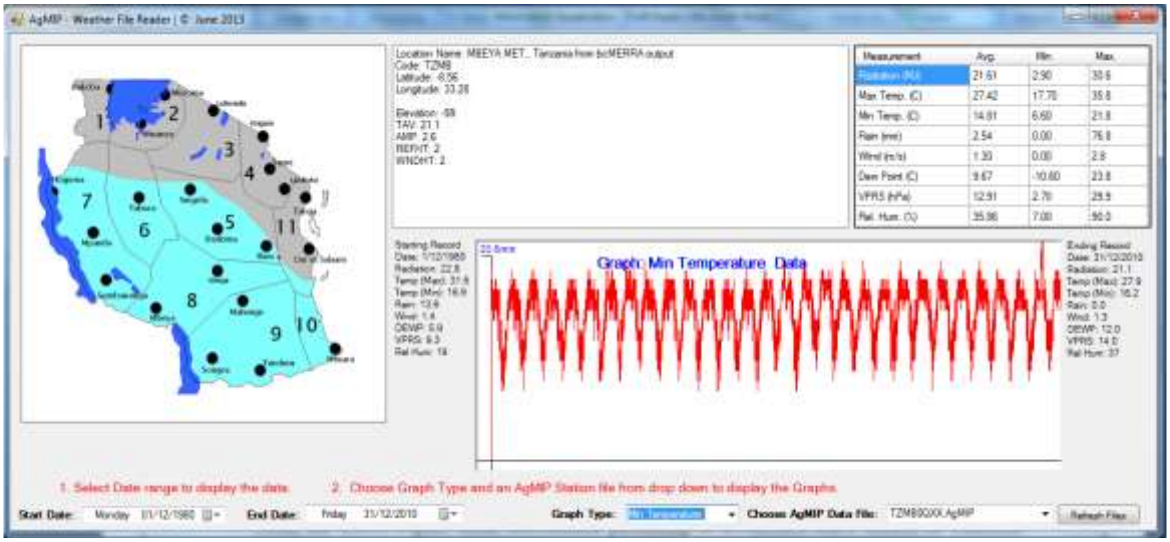


Figure 2: Output for the AgMIP - Weather Data Reader for Mbeya

From the above Figure 4 which shows some information pertaining to Mbeya MET station in Tanzania is summarized. They are information about its latitude, longitude, maximum temperature, minimum temperature and maximum rainfall (among other parameters). The technique used was temporal data Abstraction (Aigner et al., 2008; Li, & Kraak, 2012). This technique is useful in depicting the pattern of large data which sometimes it is difficult to represent graphically at once. Figure 4 depict the climate data for 30 years that is why temporal data abstraction technique was used in presenting the visualization of its climate data. Its advantage is that it has wide applicability in representing different scenarios of data regardless of the origin of data. This technique is very useful for users who are experts in climate otherwise, for normal users it is difficult to understand the graphs produced by this technique.

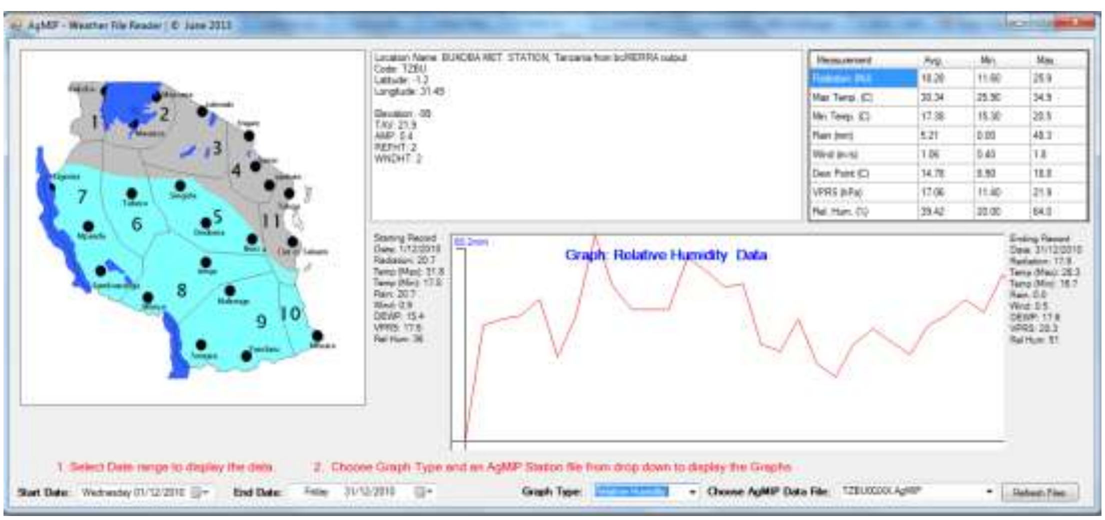


Figure 3: Output for the AgMIP – Relative Humidity Data Reader for Bukoba

In Figure 5, the technique used was principal component analysis, and clustering of larger volumes of time-oriented data. Their advantage is that the user can get the abstracted view of data very easily (Aigner et al., 2008; Li, & Kraak, 2012).

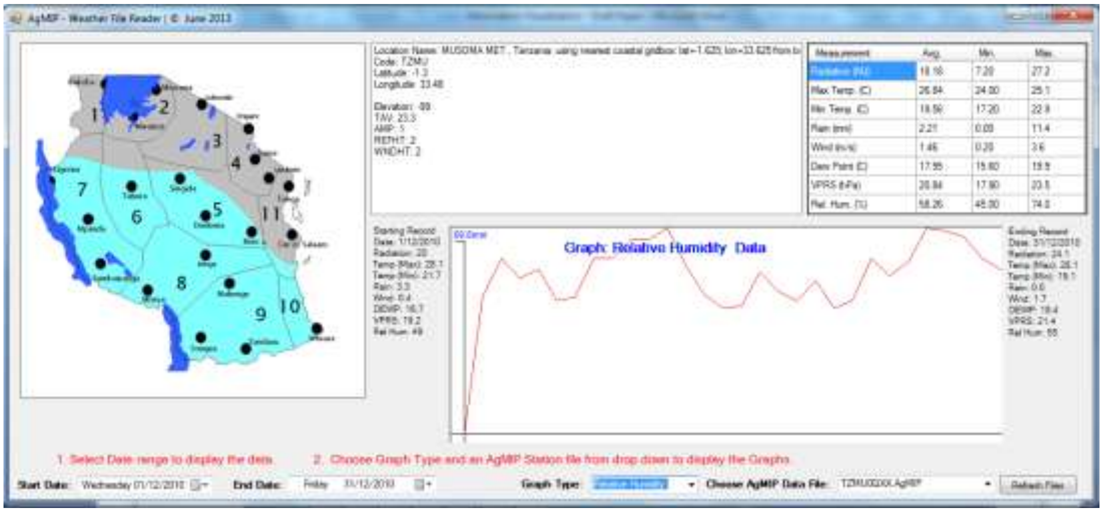


Figure 4: Output for the AgMIP – Relative Humidity Data Reader for Musoma

In Figure 6, the technique used was principal component analysis (PCA), and clustering of larger volumes of time-oriented data. Their advantage is that the user can get the abstracted view of data very easily (Aigner et al., 2008). The PCA and clustering techniques are very good for normal user because of its detailed representation of data which can be understood by novice user.

In this section, the usefulness of three techniques for climate data visualization to gain insight into larger volumes of time-oriented data has been represented. This has been done with guidelines from Aigner et al. (2008) and Li, & Kraak, (2012). Aigner et al. (2008) argue that temporal data abstraction aims at gaining qualitative high-level insights while PCA and clustering help in handling larger numbers of variables, respectively, tuples in time-oriented data. These three methods applied to large time-oriented data sets which provide different levels of abstraction and help to reveal major trends in the data are still open for research (Aigner et al., 2008; Li & Kraak, 2012).

## 11.Conclusion and recommendation

The need of tools for visualizing climate data from large data sets obtained from climate models has been studied from different previous literature. The relationship and pattern between data sets extracted from the modelled climate data is of great importance to different stakeholders who cannot visualize easily the huge amount of datasets. In this paper, we have presented the climate data visualization tool which allows interactive display of map as per multi-dimensional data sets from multiple parameters of climate data after being analysed by climate models as per needs of different stakeholders. The tool has been developed using a participatory approach which was done easily because of the use of various communication channels (i.e. workshop, writeshop, blogs, discussion forum, social media page) that supported different processes of research. The developed tool is easy to use by different categories of users. It needs no prior knowledge in order to use it. Its advantage is similar to those identified by Ladstädter et al. (2010) who argue that climate data visualization tool must have the following



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novel characteristics, namely: easy to visualize, analyze and explore features of interest such as trends, differences between datasets, or interdependencies between available parameters.

The lesson learnt from this study is that multi-disciplinary team work is very important in today's world of research. In this research, climate scientist, water resources engineer, agricultural engineer, hydrologist, gender specialist, economics experts and computer scientist worked together in understanding and then solving different problems pertaining to climate, crop, and economic modeling.

In future study, the system needs to incorporate module for integrated comparisons of climate data from different stations for visualization of data from climate, crop and socio – economic using current and future scenarios for 30 years.

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