CALL FOR INNOVATION RESEARCH GRANTS ON RESPONSIBLE ARTIFICIAL INTELLIGENCE FOR CLIMATE ACTION

Launched and managed by

The Regional Universities Forum for Capacity Building in Agriculture (RUFORUM)

in partnership with

West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL)

and AKADEMIYA2063

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Reference: **IDRC-SIDA-RUFORUM/WASCAL/A2063-IRG/2022**

Submission Deadline: May 2nd, 2022,
Deadline for submission: June 30th, 2022
(17:00 PM Eastern Daylight Time)

Submission Channel: RUFORUM Information Management System (RIMS: http://rims2.ruforum.org/)

Project Title	**Bridging critical gaps in relative humidity data to enhance climate science and services in Ethiopia: The case of Awash River Basin**
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Names of participating researchers and their institutions with full addresses including email	1. Dr. Abebe Belay Adege Institute of Technology Debre Makos University Tel, +251912003038, Email: abbblybelay@gmail.com, abebe_belay@dmu.edu.et 2. Leta Bekele Gudina National Meteorological Agency of Ethiopia Email: Letaabreham@gmail.com/ leta.b@ethiomet.gov.et 3. Emebet Wale Chanie Institute of Technology Debre Makos University Email: emebetcs2009@gmail.com Two female MA/MSc students-TBA
Project site(s) areas of intervention (Include GPS coordinates if available)	*Awash River Basin Ethiopia*
Total project budget	US$46,998
Project start date	May 20, 2023
Short specific abstract of no more than 200 words (respect the word count).	The objective of the proposed research project is to enhance climate services offered by the National Meteorological Agency of Ethiopia by filling the critical gap that NMA has in relative humidity (RH) data. The plan is to produce representative high quality gridded RH data by merging better quality satellite and reanalysis RH data from global open sources with quality control in-situ records. We plan to first evaluate the quality of global data products, then produce new one by merging the relatively better RH data with quality control in-situ records. We proposed an excellent research into-use plan by applying and testing the new data product for early drought detection ability and for human and livestock comfortability indices. Results generated from these activities including two MA/MSc Theses will be deliverable outputs from this project. We also plan to train two female students in MA/MSc. We established excellent multidiscipline expert networks (climate scientist, data expert, and expert for artificial intelligence)

	and partnership with National Meteorological Agency of Ethiopia for effective implementation.

I. Cover Page (1 Page)

Dear Sir,

Thank you for the opportunity to be considered for support by the IDRC-SIDA-RUFORUM/WASCAL/A2063-IRG/2022.

We are excited to be applying for IDRC-SIDA-RUFORUM/WASCAL/A2063-IRG/2022 as this call create excellent opportunity for young African climate scientists to use Artificial Intelligence for enhancing climate services in Africa. We aim to use this excellent opportunity to fill demand driven critical gap in relative humidity (RH) data by merging globally available gridded RH data from open sources with quality controlled in-situ records using data merging state-of-the-art method. We hope this is the first in its type that will be implemented by African climate scientists at African institution. Our research project will not end up by producing data, we have made an excellent research into-use action plan.

For effective implementation, we established excellent partnership between key institutions in Ethiopia (Debre Markos University, National Meteorological Organization and Awash River Basin Authority and Disaster Risk Management Commission) to effectively implement the proposed activities. Excellent partnership also established between multidiscipline experts that include climate and data evaluation scientist (Dr. Mekonnen Adnew Degefu), data expert (Leta Bekele) at NMA, and artificial intelligence (Dr. Abebe) at IT department Debre Markos University. Dr. Mekonnen will lead the data mining and evaluation activities, drought index generation and data evaluation activities and also lead the result communication and capacity building programmes. NMA will be our key partner as a source of in-situ RH data, source of experts and center for data merging activities, data archiving, data user and distributer for the new RH data product.

We plan to first evaluate the quality of global data products, then produce new one by merging the relatively better RH data with quality control in-situ records. We proposed an excellent research into-use plan by applying and testing the new data product for early drought detection ability and for human and livestock comfortability indices. Results generated from these activities including two MA/MSc Theses will be deliverable outputs from this project. We also plan to train two female students in MA/MSc.

Thank you for your consideration. We look forward to hear positive outcomes from proposal evaluation teams.

Sincerely,
Dr. Meknnen Adnew Degefu (on behalf of all the applicant)

Executive Summary (500 words maximum)

Provide a succinct summary of the Project. Please note that this summary will be provided to the evaluators for review and should provide a clear summary of the project including rationale, objectives, outputs to be delivered by the project and potential impacts to be achieved.

1. Currently there is a growing demand for representative and accurate climate services among policy makers, practitioners and end users across the world, due to the widespread effects of climate risks. The demand is extremely high in the data poor sub-Saharan African countries as this region has not only has low adaptive capacity, but also does not have representative and quality scientific information to prepare for and to formulate sound climate risk management policies and climate services. The objective of the proposed research project is to enhance climate services by filling critical gap in relative humidity data for NMA. The plan is to produce representative high quality gridded relative humidity data by merging better quality satellite and reanalysis RH data from global open sources with quality control in-situ records. We plan to first evaluate the quality of global data products, then produce new one by merging the relatively better RH data with quality control in-situ records. We proposed an excellent research into-use plan by applying and testing the applicability of the new data product for its ability of early drought detection and for human and livestock comfortability indices use. Results generated from these activities including two MA/MSc Theses will be deliverable outputs from this project. We also plan to train two female students in MA/MSc. We established excellent multidiscipline expert networks (climate scientist, data expert, and expert for artificial intelligence) and partnership with National Meteorological Agency of Ethiopia for effective implementation.

1. Background and rationales to the research project

Currently there is a growing demand for representative and accurate climate services among policy makers, practitioners and end users across the world, due to the widespread effects of climate risks. The demand is extremely high in the data poor sub-Saharan African countries as this region has not only has low adaptive capacity, but also does not have representative and quality scientific information to prepare for and to formulate sound climate risk management policies and climate services (Dinku et al., 2014; ACPC, 2013; Vogel et al., 2019). This basic lack of information and services in Africa is largely attributed to the scarcity of representative ground observation, lack of accessibility due legal restrictions, low dissemination capacity or high access costs (Washington et al., 2006; Dinku, 2019). The existing ground-based data also suffer from quality problems (e.g., missing and poor accuracy and precision) (Dinku et al., 2019). Hence, addressing these challenges should be the priority intervention area to deliver sound climate service in Africa (ACPC, 2013; WMO/WCSP, 2014).

Currently there is very big opportunity for data poor countries like Ethiopia to overcome the scarcity of historical data due to the emergence of remote sensing, model reanalysis and extrapolation of in-situ data (AghaKouchak et al., 2015) as these data products provide information with continues spatial and temporal coverages and free of charge. However, the application of these climate products is at early stage in Africa for many reasons. Evidences, confirmed that most of the global and regional scale climate products have used limited number of ground observation for production or verification, hence most of them reveal significant error and bias, particularly in mountainous east African countries (AghaKouchak et al., 2015). There is also critical human capacity, technology and innovation gaps to exploit data from global big-data sources, and to analyse gridded data products that require new tool and machine (Dinku et al., 2014). Recently, data merging/assimilation state-of-the-art method has created a new avenue to enhance to representativeness and accuracy of data from these sources. This innovation has enables to produce high quality gridded data by combining satellite or model reanalysis products with quality controlled in-situ observation. This innovation enables to produce high quality data by combining the strength and minimize the weakness of in-situ data (high accuracy and low spatial representation) and satellite and model products (high spatial representation and low accuracy (Dinku et al., 2017). The Ethiopia National Meteorological Agency (NMA) in collaboration with the International Research Institute for Climate and Society (IRI) has used this innovation produced high resolution (0.04°) precipitation and temperature data by merging Thermal Infrared satellite observation with in-situ records for 500 stations (Dinku et al., 2014), and this data is superior in quality and significantly enhance the representativeness and accuracy of climate services offered by NMA. By understanding its advantage, NMA now need to have gridded data particularly for scarce climate variables such as (relative humidity, PET, and wind) to produce and deliver improved climate services for all key sectors (health, water, agriculture and disaster risk management).

This research project is strongly align with the thematic areas of the call for AI for climate action Innovation research project as our research project intends to produce new climate data to enhance climate services by applying AI state-of-the-art method and enhance the capacity young African. The proposed project is highly relevant to the local and national climate research priorities, as well as to the priorities of African Union's Agenda 2063, UN Sustainable Development Goals (SDGs) and the Paris Climate Agreement on Science, Technology and Innovation, and Capacities building requirement for climate science in Africa. The results will primarily benefit NMA and climate researchers as it enable to get better data to produce quality basin scale climate service. NMA as the main partner to this research project intends to use the new data to improve the delivery of climate services in the health sector (e.g., malaria, heat stress, drought forecasting etc.), agriculture, water and disaster risk management actions.

2. Literature Review

The emergence of satellite observation and numerical climate prediction model products created unique avenue for data poor sub-Saharan African countries as these data sources providing information with a global coverage at good spatial (0.5 to higher) and temporal resolution (hourly, daily and monthly) free of charge. Over these, the emergence of data merging/assimilation state-of-the-art method has been opening a new avenue for data poor region (Lahoz and Schneider, 2019). Merging satellite or model estimates that have better spatial coverage with in-situ data that have better accurate measurement and temporal coverage has become the most promising approach to produce good quality gridded hydro-climate dataset that can well represent both the temporal and spatial variations of hydro-climate over regions of insufficient gauge density (Lahoz and Schneider, 2019). Improving data availability requires addressing spatial and temporal gaps in existing climate observations as well as the quality of the data. The main strength of satellite products is that they provide good overall spatial coverage. However, these products have their own weaknesses, which include short record length, coarse spatial and temporal resolutions, inhomogeneity of the time series, and either poor accuracy (Dinku, 2019).

This innovation enables to produce high quality data by combining the strength and minimize the weakness of in-situ data (high accuracy and low spatial representation) and satellite and model products (high spatial representation and low accuracy (Dinku et al., 2017). This approach is largely used to improve precipitating data at global scale (e.g., CHIRPS; Funk et al., 2015) and for Africa (ARC2, RFE2 and TAMSA; Tarnavsky et al., 2014). The presence of multitude of global open-source data sets enables comparison, and therefore to select the relatively better data products to further improve its quality by assimilating with more accurate in-situ measurements. Large developments have been taken place in this avenue to improve the representativeness and quality of rainfall data, both globally (e.g., CHRIPS; Funk et al., 2015) and in Africa (e.g. TAMSAT, ARC2 and RFE2; Le Coz and van de Giesen, 2020). However, little no work has been implemented to use this state-of-the-art-method to the other scarce climate elements such as relative humidity, evapotranspiration, wind, solar radiation, etc.

Globally, there are some satellite based RH data. Some of these are Atmospheric InfraRed Sounder (AIRS; Aumann et al., 2003), Free Tropospheric Humidity (FTH) (Schröder et al., 2014), and Sondeur Atmosphérique du Profil d'Humidité Intertropical par Radiométrie (SAPHIR, Brogniez et al., 2016) products. National Centers for Environmental Prediction (NCEP)–National Center for Atmospheric Research (NCAR) (NCEP/NCAR; Kalnay et al., 1996), Modern-Era Retrospective analysis for Research and Application version 2 (MERRA2: Rienecker et al, 2011), Japanese 55-year Reanalysis (JRA-55 Kobayashi et al., 2015), European Centre For Medium-Range Weather Forecasts ReAnalysis (ERA5; Albergel et al., 2018), and Daily surface meteorological data set for agronomic use, based on ERA5 (AgERA5; WEnR, 2019). All these datasets created "very big global data constellation" and are freely available for researchers and practitioners. But representativeness and accuracy of these data products for local application are not well evaluated in Africa. Again, most satellite-based observation have short record lengths, while reanalysis products offer long record length back to the 1980s (Abatzoglo et al., 2017). Ground observation on the other hand provides accurate measurement, but spatially incomplete and temporally inconsistent, particularly in the data poor African countries. Currently, the state-of-the-art of data blending provides unique opportunity to create a representative and relatively accurate RH data by merging one or more of the global gridded data with the more accurate gridded data. Evidences confirmed that a combined use of satellite, reanalysis and in-situ observations can improve the quality hydroclimate data by counterbalancing the weakness and advantages of the input datasets (Funk et al., 2015Cooper et al., 2019).

3. Objectives

The overall objective of this research project is to enhance the availability and utilization relative humidity (RH) data by exploring from global open data sources and producing new one by merging data from global sources and in-situ records through data merging state-of-the-art method for Awash River Basin in Ethiopia. The specific objectives of the proposed research project are to:
The specific objectives of the proposed research project are to:

i. Exploring and evaluating daily time scale global RH data (satellite, in-situ-interpolated, and model reanalysis) from open multiple global sources,
ii. Producing high quality gridded RH data by merging one or more selected global RH data with quality controlled in-situ records from relatively dense stations for Awash River Basin, and
iii. Testing the applicability of the new data for its performance in capturing early onset of drought episodes and in using for human and livestock comfortability indices.

The proposed research project intends to explore and test global RH data products, and produce demand driven, original and high quality RH data by merging in-situ observation with multisource products using data merging state-of-the-art method for data poor country, Ethiopia. This research project intends to benefit from the current hydro-climate data innovations (satellite proxies and model reanalysis) to bridge critical data gaps in the developing countries. And results generated from this study will largely assist the development of science informed climate mitigation and adaptation strategies in Ethiopia. Results generated from the proposed study will have multifaceted benefits both for science and practice. In addition to this, evaluation on the performance of RH can provide valuable feedbacks global data producers to advance data production algorisms and methods. The proposed research project intends to significantly enhance the climate research capacity of young academicians. The results generated from this research project can be an excellent lesson for the remaining data poor sub-Saharan African countries.

4. Key Research Questions

The proposed research project seeks to answer the following research questions:

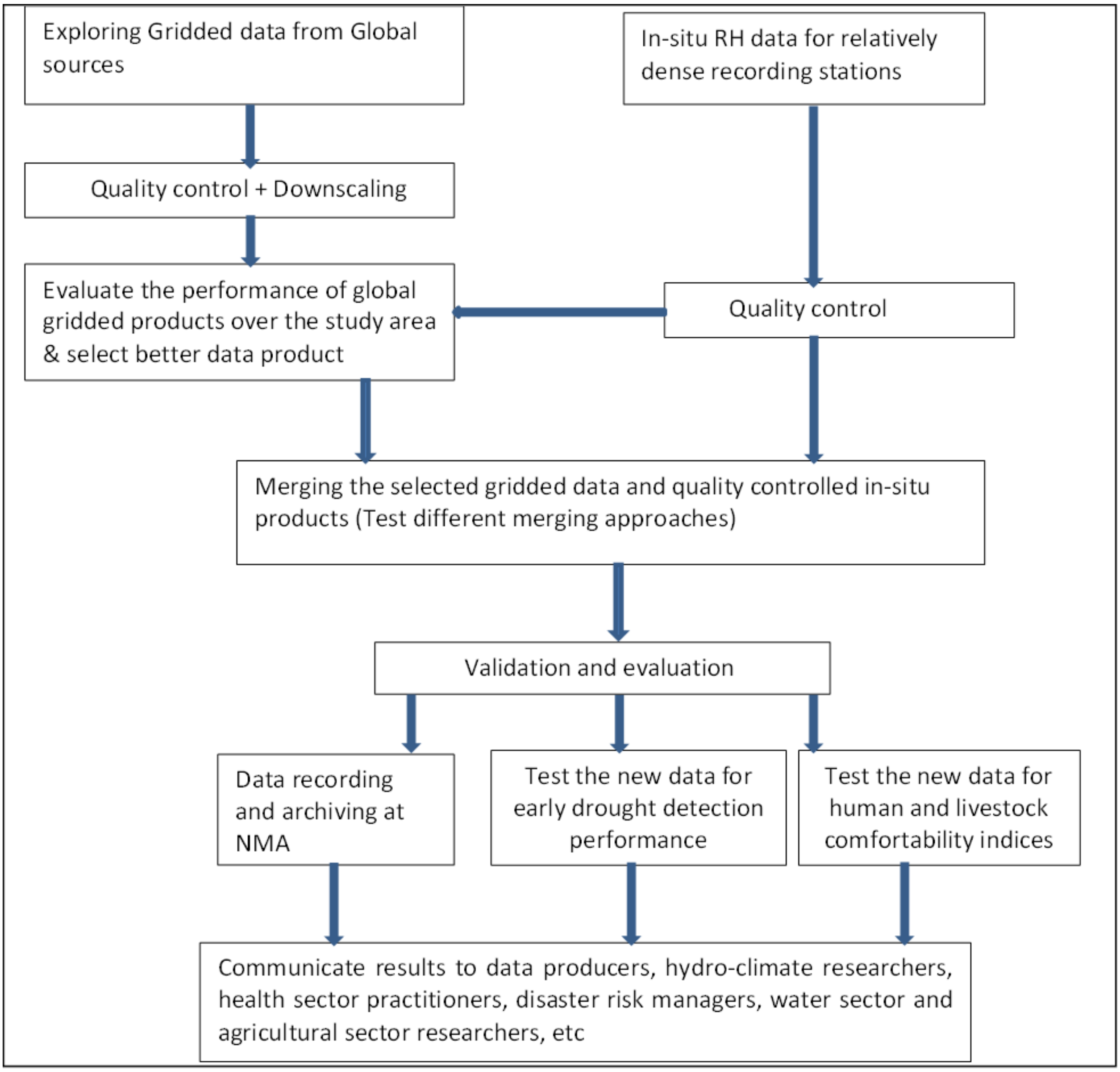
1. Which global precipitation data product has better performance in representing the spatiotemporal variability of RH characteristics including extreme events for Awash River Basin?
2. Does the AI data merging state-of-the-art method can enhance the spatiotemporal representation and quality of RH data for Awash River Basin?
3. How the newly produced RH data will be useful in detecting the onset of drought episode earlier than using precipitation data (SPI) and for human and livestock comfortability indices?

4. Research Approach and Conceptual Framework

We proposed a transdiscipline (working together with stakeholders) approach to effectively implement the proposed research activities. To enable this approach to put on the ground, need assessment was conducted among key stakeholders, these include the Artificial Intelligence centre at Debre Markos University (Dr. Abebe), climate data management experts (e.g. Leta Bekele) and Deputy Director (Kinfe Hailemariam) at the National Meteorological Agency (NMA) of Ethiopia and climate researchers at Awash River Basin. We also consulted some young hydroclimate researchers at Debre Markos University for their need for trainings on climate related issues. Hence the proposed research area was selected by consulting these key stakeholders of the proposed research project and the key stakeholder (NMA) for climate data collection, analysis and distribution. The proposed research project therefore is developed in collaboration with these experts and institutions. We reach on consensus to implement the in-situ data quality control and data merging activities at NMA using its experts. Sufficient budget is allocated for these and other activities such as data achieving and use. The plan is to implement the proposed research activities by applying multidiscipline approach that includes climate scientists, climate data expert and experts in Artificial Intelligence. We will also train and supervise two female MA/MSc students who will conduct their research on selected climate related issues using the new data product.

Our work will start by establishing formal partnership through memorandum of understanding and work agreement between key stakeholders and multidiscipline experts, respectively (e.g., Debre Markos University, National Meteorological Organization). Dr. Mekonnen Adnew Degefu, a climate scientist at Debre Markos University will lead the overall implementation of the research project. He will also lead the exploration, mining and performance evaluation of global RH data products. Data obtained from various sources will be checked for their quality and accuracy (e.g., missing data etc). Then these data will be downscaled and regridded into selected high spatial resolution (e.g., 0.04°) and evaluated for their performance in representing the spatio-temporal condition of RH for the study area. In-situ data for relatively dense station networks at NMA will be checked for their quality (e.g., missing data, homogeneity, outlier, lat lon verification, etc) by NMA climate data experts in collaboration with the lead researcher. Then, we will evaluate the global gridded data products for their performance in representing the spatio-temporal conditions of RH for the study area. This activity enables us to select one or more gridded data product that will have relatively better performance over Ethiopia to use as input data for the production of new RH product by merging with in-situ product. After selecting a relatively better representative gridded RH data product, we plan to produce new RH data by merging the selected gridded RH data with quality controlled in-situ data records by NMA experts (Leta) and lead researcher. We have a plan to apply and test multiple methods of data merging algorisms that include a Bayesian kriging approach (Verdin et al., 2015), simple bias adjustment and regression kriging (Dinku et al., 2014), and Kalman Filter assimilation techniques (Cooper et al., 2019) at selected spatial resolutions (0.04^{o}) and time daily time scale. As used in many similar works (e.g. Dinku et al., 2014), leave-one-out cross-validation will be used to assess the performance of data blending algorism using the statistical measures from Stage 1. We will also facilitate the implementation of research into-use action. After testing its quality, the new data together with other pre-existing gridded products e.g., rainfall and temperature will be applied and tested for their performance for early detection of drought episodes by the lead researcher and for the generation of human and livestock comfortability indices by NMA experts (Leta).

We planned to apply excellent capacity building programme for the research team member, two female MA/MSc students. Both of these postgraduate training chances will be given to female experts at NMA and or Debre Markos University. The research capacity and skill of the research team members and MA/MSc students will be enhanced by implementing on the ground research, supervision and training programmes.


Exploring Gridded data from Global sources
In-situ RH data for relatively dense recording stations
Quality control + Downscaling
Evaluate the performance of global gridded products over the study area & select better data product
Quality control
Merging the selected gridded data and quality controlled in-situ products (Test different merging approaches)
Validation and evaluation
Data recording and archiving at NMA
Test the new data for early drought detection performance
Test the new data for human and livestock comfortability indices
Communicate results to data producers, hydro-climate researchers, health sector practitioners, disaster risk managers, water sector and agricultural sector researchers, etc

5. **Methodology**

Data and sources

We have already identified global gridded RH input data from various open data sources (Table 1). These gridded data products are freely available and can be downloaded from internet or from their data portal through application. In-situ RH data is available at NMA for relatively dense network recording stations.

Table 1. Description of input RH data and sources

Data type	Data description	Source	Spatio-temporal resolution
1. Hadley Center Integrated Surface Database Humidity (HadISDH; Willett et al., 2014)	In-situ interpolated	UK Met Office	5° x 5°, monthly, 1973-present
2. European Centre For Medium-Range Weather Forecasts ReAnalysis (ERA5; Albergel et al., 2018)	Reanalysis	Copernicus	0.28° x 0.28°, daily, 1979-present
3. Daily surface meteorological data set for agronomic use, based on ERA5 (AgERA5; WEnR, 2019)	Reanalysis	Copernicus	0.01° x 0.01°, daily, 1979-present
4. Atmospheric InfraRed Sounder (AIRS; Aumann et al., 2003)	Satellite proxy	NASA	1° x 1°, monthly, 2002-present
5. Sondeur Atmosphérique du Profil d'Humidité Intertropical par Radiométrie (SAPHIR; Brogniez et al., 2016)	Satellite proxy	ICARE	1° x 1°, monthly, 2011-present
6. National Centers for Environmental Prediction (NCEP)–National Center for Atmospheric Research (NCAR) (NCEP/NCAR; Kalnay et al., 1996)	Reanalysis	NOAA	2.5° x 2.5°, daily, 1948-present
7. Japanese 55-year Reanalysis (JRA-55; Kobayashi et al., 2015)	Reanalysis		1.25° x 1.25°, daily, 1958-present
8. Modern-Era Retrospective analysis for Research and Applications version 2 (MERRA2; Bosilovich et al., 2016)	Reanalysis	NASA	0.625°×0.5°, daily, 1979-present
Reference data			
1. In-situ RH data for many station over Ethiopia	In-situ	NMA Ethiopia	Station (~250)
2. ENACT rainfall data (to generate SPI which will be used to compare the drought detection ability of RH data	Reanalysis	NMA-Ethiopia	0.04°×0.04°, monthly, 1983-present
3. In-situ temperature data for many station over Ethiopia	In-situ	NMA Ethiopia	Station (~150)

Data analysis

Brief description on the proposed methods is sequentially presented below for each research objective. **Stage 1**: For the first objective, available gridded RH data from various sources will be downscaled and evaluated for their performance against quality controlled in-situ observations over Ethiopia. Performance will be evaluated in a spatially and temporally explicit manner not only correlation, Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Index of Agreement (IA), Critical Success Index (CSI), Probability of Detection (POD), missing Rate (MR) and False Alarm Rate (FAS). The RH products that perform best statistically will be merged with in-situ observation (Stage 2) to produce the new gridded RH product.

Stage 2: New RH data will be produced by merging in-situ observation with the gridded product(s) that perform best over Ethiopia. Data merging will be conducted in two ways: 1) merging in-situ RH data with the selected individual gridded data and 2) with their ensemble after calibrating the selected datasets using in-situ RH datasets. We have a plan to apply a simple bias adjustment and regression kriging data merging algorism (Dinku et al., 2014) at selected spatial resolutions (0.5^{o} or 1^{o}) and time scales (daily or monthly). As used in many similar works (e.g. Dinku et al., 2014), leave-one-out cross-validation will be used to assess the performance of data blending algorism using the statistical measures from Stage 1.

Stage 3: Testing the applicability of the new data for its performance 1) in capturing early onset of drought episodes and 2) generating accurate comfortability indices generation for human and livestock.

1) We will generate drought index using Standardized Relative Humidity Index (SRHI: Farahmand et al., 2015). The drought index generated from this analysis will be compared against results generated using the customary drought monitoring method that is Standardized Rainfall Index (SPI). SPI drought index will be generated from in-situ precipitation records collected for the study area. The SRHI then will be evaluated for its ability in representing the atmospheric background information for rainfall occurrence; hence its ability in detecting drought occurrences earlier than the precipitation based SPI method by taking at least 3-4 major historical drought incidents. We will also evaluate its ability in representing drought frequency, magnitude and spatial coverage. We will apply a quasi-objective (visual inspection) and all the statistical evaluation measurements indicated in Stage 1 to evaluate the performance new data for drought monitoring.
2) To test the applicability of the new data for generating reliable comfortability indices for human and livestock, we plan to use Temperature Humidity Index (THI) to calculate the human and livestock comfortability index as follows:

THI = 0.8*T+ RH*T/500 for Human
THI =0.8*T + RH*(T-14.4) + 46.4 for livestock
The results can be interpreted as follows: Not Stressed (<68), Stressed threshold (68 to 71), Mild (72 to 79), Moderate (80 to 89), Severe (90 to 99), and Dead Cows (>=100).

Results will be compared with the human and livestock comfortability indices generated from the customary in-situ based measurements. The statistical measurement indicated Stage 1 will be used to evaluate the performance of new data for human and livestock comfortability indices.

The two MA/MSc students will conduct their research on the gender implications of climate services in the Awash River Basin. The research activity will include 1) the spatiotemporal variability of RH in the study area and the implications for socially differentiated groups, and 2) the applications of climate services by socially diversified groups in the study area.

Proposed implementation plans
We already established excellent partnership between key institutions in Ethiopia (Debre Markos University, National Meteorological Organization and Awash River Basin Authority and Disaster Risk Management Commission) to effectively implement the proposed activities. Excellent partnership also established between multidiscipline experts that include climate and data evaluation scientist (Dr. Mekonnen Adnew Degefu), data expert (Leta Bekele) at NMA, and artificial intelligence (Dr. Abebe) at IT department Debre Markos University. Dr. Mekonnen will lead the data mining and evaluation activities, drought index generation and data evaluation activities and also lead the result communication and capacity building programmes. NMA will be our key partner as a source of in-situ RH data, and experts, data archiving, data user and distributer for the new RH data product. Hence, Leta Bekele, a data expert at NMA will lead the in-situ data quality control and data merging work together with Dr. Mekonnen climate expert. And Dr. Abebe who is an expert for artificial intelligence will support the AI application and capacity building activities. Leta Bekele will also lead the data

archiving work and making a suitable environment for sustainable data management at the NMA online data portal.

The two female MA/MSc students will work their MA Thesis research on preselected topic. One of the student will work on 1) the spatiotemporal variability of RH in the study area and the implications for socially differentiated groups, and 2) the applications of climate services by socially diversified groups in the study area. The other student will work on spatiotemporal variability of human and livestock comfortability indices over the study area, and the implications among socially diversified groups. These students will closely work with the lead researcher and other research team members in drafting objectives, research methodologies and the overall implementation of their Thesis.

6. **Description of the Innovation**

The emergence of satellite observation and numerical climate prediction model products created unique avenue for data poor sub-Saharan African countries as these data sources providing information with a global coverage at good spatial (0.5 to higher) and temporal resolution (hourly, daily and monthly) free of charge. Over these, the emergence of data merging/assimilation state-of-the-art method opens a new avenue for data poor region (Lahoz and Schneider, 2019) as it merging satellite or model estimates that have better spatial coverage with in-situ data that have better accurate measurement and temporal coverage has become the most promising approach to produce good quality gridded hydro-climate dataset that can well represent both the temporal and spatial variations of hydro-climate over regions of insufficient gauge density (Lahoz and Schneider, 2019). The presence of multitude of global open-source data sets enables comparison, and therefore to select the relatively better data products to further improve its quality by assimilating with more accurate in-situ measurements. Large developments have been taking place in this avenue to improve the representativeness and quality of rainfall data, both globally (e.g. CHRIPS; Funk et al., 2015) and in Africa (e.g. TAMSAT, ARC2 and RFE2; Le Coz and van de Giesen, 2020). The National Meteorological Agency (NMA) of Ethiopia in collaboration with International Research Institute for Climate and Society (IRI) of Columbia University have produced high quality (4 km resolution and daily time step) rainfall and temperature data products by merging quality controlled in-situ observation with satellite proxies (Dinku et al., 2014). The proposed research project intends to apply this state-of-the-art data production method to fill gaps for the most scarce climate variable (i.e., RH) for Ethiopia. We strongly believe that the primary intervention area in climate response in Africa should be finding or producing representative climate data to generate representative and accurate climate information for policy makers, practitioners and other end users. Such innovation and application is very likely to be scale-up to fill data gaps for the other hydro-climate variables and to the other part of data poor African countries.

The other innovation is that this research work is demand driven, co-designed with the main stakeholder of NMA, which is responsible for all aspects of climate data collection, processing and distribution in Ethiopia. Hence, the proposed activities will not only effectively implemented, but also the results can be immediately used for operational actions. In addition to this, the proposed project is highly relevant to the local and national climate research priorities, as well as to the priorities of African Union's Agenda 2063, UN Sustainable Development Goals (SDGs) and the Paris Climate Agreement on Science, Technology and Innovation, and Capacities building requirement for climate science in Africa. This is because, our research projects not only targeting to produce climate data, but also introduce new skill and experiences as well as innovation in data miming from global sources, data evaluation, data merging state-of-the-art method and artificial intelligence in climate knowledge generation and services. It is also important that the proposed research project will create excellent platform and lesson to apply data merging state-of-the-art method for the other scarce hydro-climate data gap filling (wind, PET, soil moisture and runoff) in the data poor regions.

7. Impacts

We will apply a transdiscipline approach (working closely with key stakeholders) and implement activities by experts from multidiscipline (e.g. climate science, data science, artificial intelligence). Hence, the results generated from this study expected to benefit many sectors and contribute its part in filling critical data and information gaps for the study area. Hence our study can enhance the availability and access to the most scares climate element (RH) for climate researchers and practitioners. Particularly, NMA can get representative and good quality data to generate representative and accurate monitoring and forecasting as well as early warning information in the area of health (e.g. malaria and heat stress comfortability), and drought monitoring and forecasting. The Awash River Basin Authority can get representative and ground-truth information on the spatiotemporal characteristics of RH condition to develop relevant climate change response actions for different sectors. Our proposal also contain excellent plan to address gender balance both in our research team (two of the MA students will be female), and among training participants. The two MA students will also assess the gender implication of results on their spatiotemporal analysis of RH and comfortability indices. They will conduct their research on 1) the spatiotemporal variability of RH in the study area and the implications for socially differentiated groups, and 2) the applications of climate services by socially diversified groups in the study area. In addition to these, the new RH data will create suitable environment for researchers and practitioners to generate and offer gender sensitive climate services for marginalized communities who did not have meteorological recording stations in the previous time. In addition to this, the proposed research project expected to enhance partnership between Debre Markos University, NMA, Awash River Basin Authority and other institutions in the country as well as with the funding agency.

8. Gender and inclusion

This research project contains excellent platform to represent equitable gender balance between women, man and young academician in the research team. Half of the research team (one co-researcher and two MA students) are female, and all members of the research team except the lead researcher are young. Moreover, the results generated from this study largely benefit the vulnerable rural communities where there is no representative meteorological record in their area. Hence, the proposed study will generate representative and accurate data for their area, means these people will get representative and accurate weather forecast information. Local practitioners will also get accurate climate information to develop gender sensitive various climate change adaptation strategies for the local people. We will also encourage the two MA Theses to account gender implications in their research work.

9. Responsible Artificial Intelligence in Climate Science

The proposed research project intends to fill critical gaps in climate data to generate useable climate knowledge to foster the application and development of science informed vibrant climate change adaptation policy and action. It also intends to build the research capacity of young academician on climate data mining, data evaluation, and the application of Artificial Intelligence for climate data production and climate analysis. Therefore, proposed research project will not have any negative consequences on human labor market, on environmental resources, political and social values. Rather it will create unique opportunity to enhance the transfer of innovation, technology and knowledge and enhance the research capacity of young academicians in Ethiopia. The data production will considers all the rules and restricting presented for open access satellite and model reanalysis data products. As the proposed research project also will be implemented in collaboration with NMA, we will implement all our activities by considering the rules and regulation of NMA's data production. Hence, we can ensure that the proposed research project will not induce any risk to human beings, organization, environment and other socioeconomic affaires.

10. Deliverables and expected results

We intend to produce the following research results outputs and deliverables:

1. Evidence report document on the performance of global RH data products for the study area (Awash River Basin). This report will also be published in peer reviewed journal.
2. New high quality RH data generated and archived at NMA data portal based on NMA data policy. Document report also generated that explain the process of production and data quality description. This will again be published in peer reviewed journal.
3. Two other research reports that evaluate the performance of the new RH data for 1) drought monitoring and early detection of drought onset for the study area and 2) human and livestock thermal comfortability index as compared to the customary methods. We plan to produce one or two journal publications from these.
4. Two MA/MSc Thesis on 1) the spatiotemporal variability of RH in the study area and the implications for socially differentiated groups, and 2) the applications of climate services by socially diversified groups in the study area.

Overall the results generated from this research very likely enhance data availability and access to climate researchers and practitioners and also enhance the research capacity of young academicians. It will also contribute its part in narrowing the gender bias by training more young female academicians.

11. Dissemination and communication

We identified key message or contents, target audiences and excellent methods of result communication methods. See the details in Table 2.

Table 2: Methods for dissemination of BRDIOM-Ethiopia results tailored to individual target audiences

Target audience	Key messages/content and goals	Main methods
Global hydro-climate data producers and international hydro-climate research communities (e.g. Copernicus, ECMWF NASA, UK Hadley Center, NOAA, etc)	Evidences on the performance of the available gridded RH products, quantify uncertainties and evidences on the performance of RH data merging algorisms. The results will help them to further improve their data and data merging algorisms.	Publications in peer reviewed journals (2-3), local workshop, and social medias (e.g. blogs, LinkedIn and tweets_2-5)
Key actors in NMA of Ethiopia (e.g. biometeorology, agronomy, hydrometeorology, climate forecast departments), Awash River Basin Authority, Ministry of Health's etc.	Evidences on the performance of the available gridded RH products, quantify uncertainties and evidences on the performance of RH data merging algorisms. Introduce the new RH data and facilitate data archiving, distribution and create a platform to use and test the new RH data early drought detection and human and livestock comfortability index	Communicate results via the network that I already established with experts and NMA directors. Publish in NMA newsletter Peer reviewed journal publication (2-3 as mentioned above)
Local hydro-climate researchers, academicians and young postgraduate students at local universities and practitioner institutions	Create awareness, and communicate data availability at "big data centres", and on the advantage of data merging methods and algorisms. Introduce the new RH data, and its performance for early detection of drought and on human and livestock comfortability indices.	Distribute brochure and infograph, newsletter and social medias. Peer reviewed journal publication (2-3 as mentioned above)
Researchers and policy makers in the other data poor drought prone regions	Show data availability at global "big data centres" and create awareness on the availability of data merging methods and algorisms	Peer reviewed journal publication (2-3 as mentioned above) and workshop (regional or global work)

12. Sustainability

Our research project intends to generate new data by merging globally available RH data from open sources with quality controlled in-situ records. We also develop excellent plan to translate research results into-use action in order to show its utility for operational action in the area of climate service delivery by NMA. We have established excellent network with NMA and allocate sufficient budget to efficiently implement our plan. It is important to note that the results generated from this research will provide significant contribution to the national government and Awash River Basin Authority to develop and introduce various short-term, medium-term and long-term climate repose actions. Hence the produced new data will be used sustainably for research and operational actions to deliver representative and accurate climate services to multiple sectors (health, agriculture, water, disaster risk management, etc). In addition to this, the innovation f merged data production state-of-the-art method is very likely to be used sustainably to produce improved data products for the other scarce climate variables (e.g., PET, wind, radiation, etc) in Ethiopia and elsewhere in the data poor sub-Saharan African countries.

13. Project Management

i. Team organization and qualification

We have already established excellent multidiscipline partnership to efficiently implement the proposed research planning. The research team consists of climate scientist, climate data expert from NMA, and ICT expert for Artificial Intelligence. Dr. Mekonnen Adnew Degefu based at Debre Markos University is a climate scientist, and lead the overall research activities. He will also actively engaged and lead the data mining and evaluation activities, drought index generation and performance evaluation activities and also in the result communication and capacity building programmes. Leta Bekele, based at National Meteorological Agency in Ethiopia is a climate data expert. Dr. Abebe, based at Debre Markos University is an expert for artificial intelligence in the IT department. Hence, these two people will lead the production of new RH data by merging the selected gridded and in-situ RH datasets. The two female MA/MSc students will work their MA Thesis research on preselected topics. One of the student will conduct research on 1) the spatiotemporal variability of RH in the study area and the implications for socially differentiated groups, and the other student on 2) the applications of climate services by socially diversified groups in the study area. These students will closely work with the lead researcher and other research team members in drafting objectives, research methodologies and the overall implementation of their Thesis.

ii. Monitoring and evaluation per activity and time plan

For effective implementations of the stated objectives in section 3, activities are divided into the following highly interrelated working packages (WP) (Table 3). Working packages are systematically arranged and have logical coherence between them. We also identified and present activities, deliverables, milestones and time plans (Table 4).

Table 3. Description of working packages

Work package		Start month	End month
No.	Title		
1	**WP1**: Explore and evaluate the spatiotemporal performance of globally available gridded relative humidity data products over Ethiopia (objective 1)	1	4
2	**WP2**: Producing high quality relative humidity data by merging in-situ observation with multi-source products for Ethiopia (objective 2)	4	8
3	**WP3**: Facilitate the research into-use activities (objective 3)	8	12
4	**WP4**: Project communication, results dissemination and public engagement (objective 4)	1	12
5	**WP5**: Management	1	12

Table 4. Description of work packages, deliverables, milestones and overall time plan

Work package	WP1. Explore and evaluate the spatiotemporal performance of globally available gridded RH data (objective 1)	Months	1-4
Description of activities	1) Collecting gridded RH data from global data sources and in-situ RH from NMA Ethiopia (Month 1-2); 2) Downscaling and evaluating the quality of collected data (month 3); 3) evaluating the performance of gridded global RH data and select 2-3 RH datasets with better quality for the next step (Month 2-4),		
Deliverables	D1.1. Document report on collected gridded global and in-situ RH data and their quality (document report) - Month 6		
Milestones	M1.1. Completion of data collection and quality checking (Month 2) and M1.2. Conducting data analysis and data performance evaluation - Month 4		
Work package	WP2: Producing high quality RH data by merging in-situ observation with multi-source products (objective 2)	Months	4-8
Description of activities	Major activities in WP2 will include: 1) Bias correction on selected RH data and produce new RH data using data merging/assimilation algorism at selected spatial resolution (0.05^{o}) and daily or monthly time scale (Month 4-8); 4) validate the new RH data and compared with other global RH products and write-up (Month 8-10)		
Deliverables	D2.1. New gridded RH data and document report on the process and quality of the new data (Month 8)		
Milestones	M2.1.) Bias correction on selected RH data and produce new RH data (Month 12)		
Work package	WP3: Facilitate the research into-use activities (objective 3)	Month	8-12
Description of activities	Facilitating research into-use actions 1) Apply and evaluate the new RH data for drought monitoring and early detection drought episodes (Month 8-12), and 2) Apply and evaluate the new RH data for human and livestock comfortability indices (month 8-12)		
Deliverables	D3.1. Document report on the application and performance of the new data for drought monitoring and early detection of drought episodes and write-up (Month 12), and D3.2. Document report on the application and performance of the new data for human and livestock comfortability indices and write-up (Month 12)		
Milestones	M3.1. Application of the new RH data for drought monitoring and early detection of drought episodes and human and livestock comfortability indices (Month 12)		
Work package	WP4: Training MA students (Objective 4)	Month	1-12
Description of activities	1) Select two MA/MSc students who completed course work (1-2 Months), 2) Implement MA/MSc thesis work and supervision (Month 3-12)		
Deliverables	4.1. Two MA/MSc Thesis (Month 14) : 1) the spatiotemporal variability of RH in the study area and the implications for socially differentiated groups, and 2) the applications of climate services by socially diversified groups in the study area (month-12		
Milestones	M4.1. Select two MA/MSc course work completed students (2 Month),		
Work package	WP5: Project communication, results dissemination and public engagement	Month	1-12
Description of activities	1) Conduct continues result communications to data producers and research audience (Month 3-12); 2) Facilitate data archiving on NMA online data portal (Month 8-12), and 3) Produce and submitting paper for journal publication (Month after 12)		
Deliverables	D5.2. Manuscript for peer reviewed journals (Month 12-16)		
Milestones	1) Conduct research result communication workshop (Month 3-12)		
Work package	WP6: Management	Months	1-12
Description of activities	1) Research meeting and students supervision (once a month), and 2) submission of Mid-term (Month 6) and final reports (month 12)		
Deliverables	D6.1. Mid-term technical and financial reports (Month 6) D6.2. Final technical and financial reports (Month 12)		
Milestones	M6.1 Mid-term technical and financial reports (Month 7) Final technical and financial reports (Month 12)		

i. Results Framework

We present a concise narrative of the results framework with a diagrammatic illustration in Figure 2.

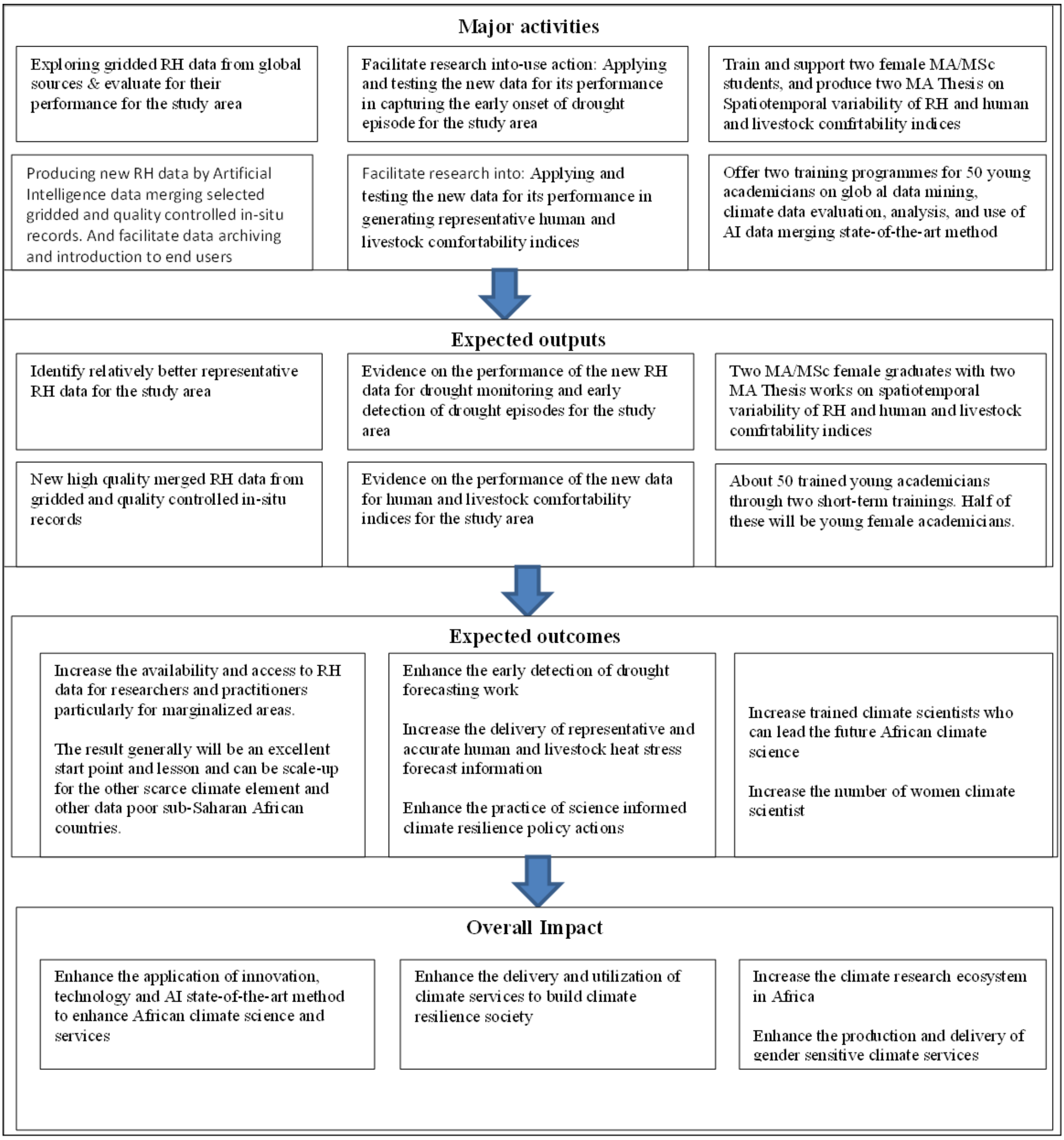


Figure 2. Illustration of workflow and concise narrative of the results framework

14. Budget description

We allocated sufficient budget for two female MA/MSc students. We allocated monthly stipend of $4800 for two MA/MSc students to be paid at monthly rate of $200/student for 12 months. We also allocated $600 ($300 per student) to cover MA/MSc thesis research work and supervision. A total of $2000 stipend) field cost for supervisors and examination. The total amount of money allocated to support these two students is about $7400.

To support various direct research activities we allocated a total amount of $23800. We have distributed this money between 6 major activities as follows:

i. We allocated a stipend of $3200 to cover cost required for global RH data exploration and evaluation works (managed by PI).

ii. About $800 money is allocated to buy in-situ RH data per the NMA data policy; ($0.81*33 stations * 30 years).
iii. We allocated a stipend of $3000 needed for experts who will make in-situ data quality control, processing and field verification (manage by Leta and PI).
iv. About $3000 money will be used to cover a stipend for experts who engage in data merging activities, calibration and validation processes (manage by Leta, PI and Dr. Abeba).
v. Cost needed to cover research communication, locally organized workshop ($3600). It is mandatory to organize at least one workshop to communicate results generate (very importantly the new data and its utility for drought detection and comfortability indices) for concerned bodies such as Awash Basin Authority, Ministry of health, agriculture and climate researchers. This budget will be used to cover expenses needed for Hall rent, refreshment, transport for participants, meal, honorarium for invited speakers, and workshop assistant.
vi. We allocated a stipend of $4800 to cover cost needed for research into-use activities that include the application and testing of the new data for 1) drought detection and early detection of drought onset ($2800, managed by the PI), and 2) human and livelihood comfortability index (stipend $2000) (managed by Leta, Dr. Abebe, and Emebet)
vii. We allocated $4400 ($50/ day/person) to cover transport costs for research member that we will use while we are travelling between Debre Markos University and Addis Ababa where our main research partner is located. The distance between these towns is 300 km.

We also allocate a total of $3260 to buy two laptops and supplies. This include, one laptop to the lead researcher which have high data capacity and processing power ($1200), and another laptop to Dr. Abebe to enable him to implement AI activities ($1200). We allocated $860 to cover costs needed for stationary materials, external hard disk, printing and copy services.

We allocate $4000 to cover costs related to Travel and Conferences. This budget is allocated to cover costs needed for RUFORUM Conference for 3 persons (2 students and PI) in two rounds ($4000). This budget can be used to cover economic class air ticket, accommodation, daily meals, visa and local transport. The other costs are related PI coordination costs, honorarium ($3500), Facilitation of partners participation in project activities ($2000) and Costs of meetings and other activities at Departmental level ($800).

We calculated indirect cost as 5% of the total direct cost and this is about $2238.

The total allocated budget including indirect cost $46998.

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