Weather risk management in Mozambique:

Technical note on current and planned weather stations and their potential viability for designing and monitoring agricultural weather risk insurance

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Contents:

1. Introduction

During April 2008 the *Africa Agriculture and Rural Development (AFTAR)* department of the World Bank undertook an identification mission for a planned market-led irrigation project in Mozambique. This project identification and preparation phase was supported by the World Bank's *Commodity Risk Management Group (CRMG)* through technical assistance on weather risk management, with technical advice to the government of Mozambique (GoM) on entry-points for weather risk management in the context of the planned project.

During the project identification phase the the Cotton Institute (CI), part of the Ministry of Agriculture (MinAg) expressed a need for technical support on commodity weather risk management to complement an initiative for a public-private partnership of the CI with cotton companies and the Instituto Nacional de Meteorologia (INAM) to install new weather stations in cotton growing areas. The weather stations will be owned by the cotton companies. Daily reading, data analysis, and modeling work to analyze the impact of weather on cotton yields will be undertaken by INAM and CI. Assistance was requested regarding (i) sharing information on similar initiatives on-going in Malawi and elsewhere, (ii) strengthening capacity to model the impact of rainfall on yields, and iii) establishing the pre-requisites for using weather data to develop weather index insurance products.

This technical note addresses aspects of these activities and needs primarily related to the installation of new stations and the potential use of existing stations for weather risk management.

1.1 Requirements for designing a weather-based insurance contract

Weather index insurance is insurance where the indemnity is based on realizations of a specific weather parameter measured over a pre-specified period of time at a particular weather station. The insurance can be structured to protect against index realizations that are either so high or so low that they are expected to cause crop losses. The indemnity is calculated based on a pre-agreed sum insured per unit of the index.

There are several advantages to weather- index insurance, as opposed to traditional forms of agricultural insurance, notably reduced moral hazard, higher transparency simplicity, and lower delivery costs. Even so, there are many requirements before weather-based insurance contracts can be designed, let alone implemented. Besides requirements related to local financial institutions and the insurance industry, the main technical requirements are:

- A demonstrable relationship between climate hazards (that can be summarised via a weather index) and crop yields needs to exist;
- A weather index should be easily understood by farmers;
- Relative risks will change depending on the crop and region and any insurance contract should reflect this;

- Basis risk (that insurance will payout to those who do not suffer damages – and vice versa) is an important limitation of weather index insurance and needs to be minimised. To minimise basis risk weather stations that represent the surrounding climatic conditions and a relatively high the density of weather station are needed;
- Accurate calculation of premium rates (the cost of insurance for the farmer) requires long and consistent weather observations– if this is not the case then any ambiguity will be reflected in higher premiums;

Other considerations include the need for a sufficient pool of farmers taking out contracts to make the scheme financially viable and the ability of any scheme to handle covariate shocks, such as those from widespread droughts which affect large areas and numbers of farmers at the same time.

1.2 Weather station site requirements

Station location requirements are based on the need to for the site to be representative of the surrounding region and to be far away from trees and tall buildings that may unduly influence the measurements. According to World Meteorological Organisation (WMO) guidelines the following applies to the different sensors:

- *Rain gauges* should be a minimum of 30 cm off the ground though higher is recommended as in-splashing may occur, especially over solid flat surfaces such as concrete (better to have gauge at > 1m). It is also recommended that they are at least four times as far away as the height of any nearby obstructions (EPA recommendation)
- *Temperature and humidity sensors* should have a ventilated radiation shield, be 1.25 - 2.0m above the ground (usually 2.0m) and preferably be > 30m from paved areas with > 9m of surrounding open space (avoiding damp hollows and vegetation);
- *Wind speed and direction* should be measured at a height of 10m and it is recommended that it is at least 10 times as far away from nearby buildings/trees as their respective height;
- *Pyranometers for measuring solar radiation* should be away from shadows and reflective surfaces and preferably on the northernmost side of the weather station (in the southern hemisphere);
- *Soil moisture* probes, where deployed, should be placed on level surfaces typical of the surrounding area (not in depressions where water may accumulate) at depths of 5, 10, 50 and 100 cm

Before installation of the weather station it is often appropriate to level the ground (though the choice of site should mostly accommodate this requirement) and set concrete foundations for any structure upon which the sensors and equipment will be placed. Additionally if the data collected at these sites are to be used for insurance purposes, the site must be secure and not accessible to the public. This often requires installation of a security fence, gates and padlocks to ensure that tampering with the data/instruments is not possible.

1.3 Data and quality control

Any data collected at a weather station to calculate an index that is related to payouts must undergo quality control procedures. Such quality control procedures are flexible and often depend on whether historical or real-time measurements are being evaluated. For example, complex statistical techniques that detect discontinuities in time series (usually indicating the relocation or deterioration of a sensor) can be used with historical data but are not appropriate for evaluating real-time data. However, some simple quality control tests can be used in both cases:

- Remove negative rainfall, or rainfall above station-specific unrealistic values;
- Remove where maximum temperatures and less than minimum temperatures or either are within 3 - 6 standard deviations of the long-term mean.

Additionally, when checking real-time data the co-evolution of different variables can be used to flag where data is not realistic. For example, temperatures generally drop with the onset of rainfall and solar radiation has an apparent daily cycle that is reduced by cloud-cover that precedes rainfall. In particular, quality control should be implemented every day to detect where any drifts or failures of sensors may be occurring. This requires that the data is either downloaded via a telecommunications network or manually downloaded every 1 - 2 days.

2. Current station network

The current station network in Mozambique, whilst appearing to be quite widespread from maps alone, suffers from missing data in the station records. Much of the missing data is found during the country's civil war between 1975 and 1992.

2.1 Station locations and density

Figure 1 shows the locations of the 33 synoptic, 13 agrometeorological (AgMet), 48 climatological and 7 automatic (AWS) weather stations. Altogether the stations are spread throughout the country mostly evenly, though there are regions noticeably not serviced by any stations e.g. Gaza province in the southwest and the central region from Quelimane inland.

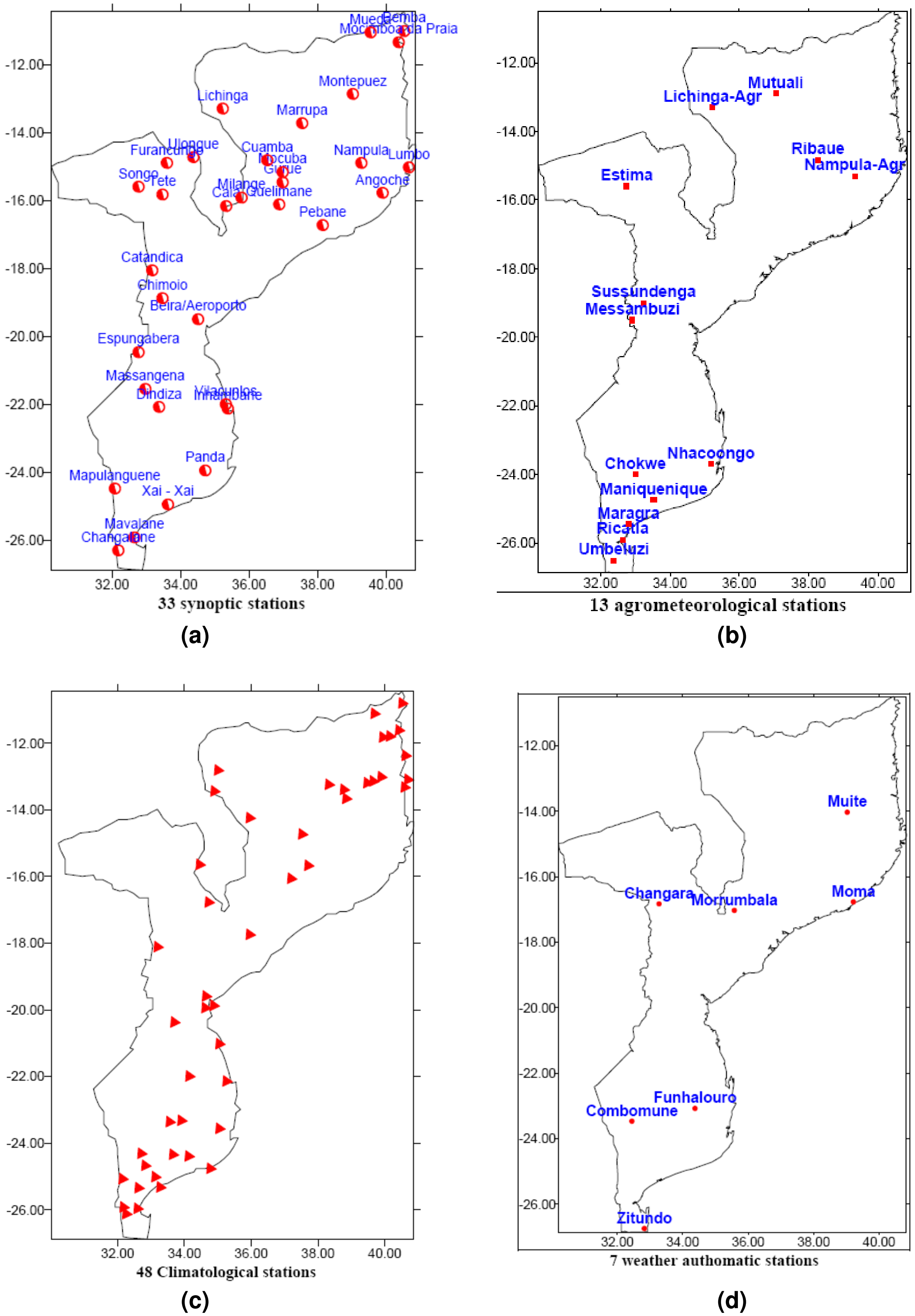

Figure 1: INAM weather station locations in Mozambique: a) 33 synoptic stations; b) 13 agromet stations; c) 48 climatological stations; d) 7 AWS. *Source INAM*.

The situation with respect to stations that may contribute to designing a weather insurance contract is more limited as all the climatological stations only report rainfall and many of them have records which finish during the 1990's or earlier. Furthermore, many of these stations are likely not suitable because they lack site security and it is not clear that the data is of sufficient quality. This is not to say that the data is not useful as it may help to fill in missing data (e.g. through spatial interpolation) or as a quality control check for nearby stations. However, as it is not likely to form the basis for designing a local weather index insurance scheme we will not consider these stations in the following discussion.

At present it is not clear how long a record there is for each of the 7 AWS stations. Whilst they are relatively new additions to the network, information provided by INAM suggests that at least some of them are expensive to maintain and replace (the cost of some AWS was reportedly in the region of €50,000). Further talks with INAM regarding their operability are required.

Of the remaining synoptic and AgMet stations it is unclear how many are still reporting and further talks with INAM would be required to make a proper assessment.

2.2 Data availability

Most of the stations, besides the climatological ones, report daily minimum and maximum temperatures in addition to rainfall. However, to what degree each station regularly reports other variables is currently unknown. Weather indexes are often constructed from rainfall alone (e.g. in Malawi) in which case long time series of other variables are not required for evaluating historical risks and designing a suitable contract. However, other index based insurance schemes have been based on a Water Requirement Satisfaction Index (WRSI), e.g. in Ethiopia, which requires an estimation of Potential Evapotranspiration (PET). Standard FAO methods for calculating PET require measured values of relative humidity, solar radiation and wind speed, though approximations are theoretically possible using measurements of temperature alone. Therefore the data requirements for evaluating an index depend on a suitable index, which is in turn dependent on the crop and location for insurance. However, it is worth noting that all the synoptic and AgMet stations should report all these variables if they have fully functional sensors and data capture systems.

2.3 Missing data

As noted before missing data is quite widespread in the records from Mozambique. However, it should be noted that this observation comes from the author's experience of looking at some of the rainfall data from climatological stations. The synoptic and AgMet stations have more reliable records as they form the core of INAMs observation network. Given the troubles for much of the 1970's and 1980's it is remarkable that so much data was collected and is a proud testimony to the dedicated observers who continued to work in difficult conditions.

At the moment it is not possible to evaluate whether the missing data is a critical problem for the design of an index insurance contract as this will depend on the crop, the index (and hence which measured variables are required) and particularly on the location of any pilot study. It should however be noted that an index can still be constructed for years without missing data (ignoring years with missing data) and so can still be usefully related to yield if there are enough full years in the record. Furthermore, there are ways of estimating missing data from nearby stations which have been used elsewhere e.g. Malawi. The feasibility of undertaking this will again depend on the location and in particular on the density of surrounding stations.

Whilst the ideal situation would be to have yield data for the locations where any insurance scheme would be piloted this is sometimes not feasible, either because the data was not collected or is not accessible. In such a case a crop model can provide estimates of potential yield. However this is not an easy task and would need to be undertaken in partnership with INAM and the relevant sections within MinAg e.g. CI or the Directorate of Agronomy and Natural Resources (IIAM).

3. Planned acquisition of automatic weather stations

As noted before the CI and INAM have already been in close discussions regarding the installation of new AWS to cover cotton growing areas with a view to possibly implementing weather-index insurance at a later date. These AWS would involve financing from Cotton companies (who would retain ownership) whilst running and maintenance would be carried out by INAM. These plans are at the stage where the approximate locations of 13 stations have been suggested. Figure 2 indicates both the agroclimatic regions suitable for rainfed production of cotton and the proposed locations of the 13 AWS. It should be noted that these locations are not finalised and an alternative map has been seen that indicates several different locations – though all are in the same general region of Mozambique. The locations are all in regions with very suitable climatic conditions and where there are currently few or no synoptic/AgMet stations (see figure 1). This has the advantage of providing climate data for regions which currently have no measurements. However, the disadvantage is that it may be difficult to generate historic data for these sites and hence develop climate index – yield relationships which can be used to design a suitable contract. Again, whether this is possible or not (including interpolating from nearby stations) will depend on the specific location.

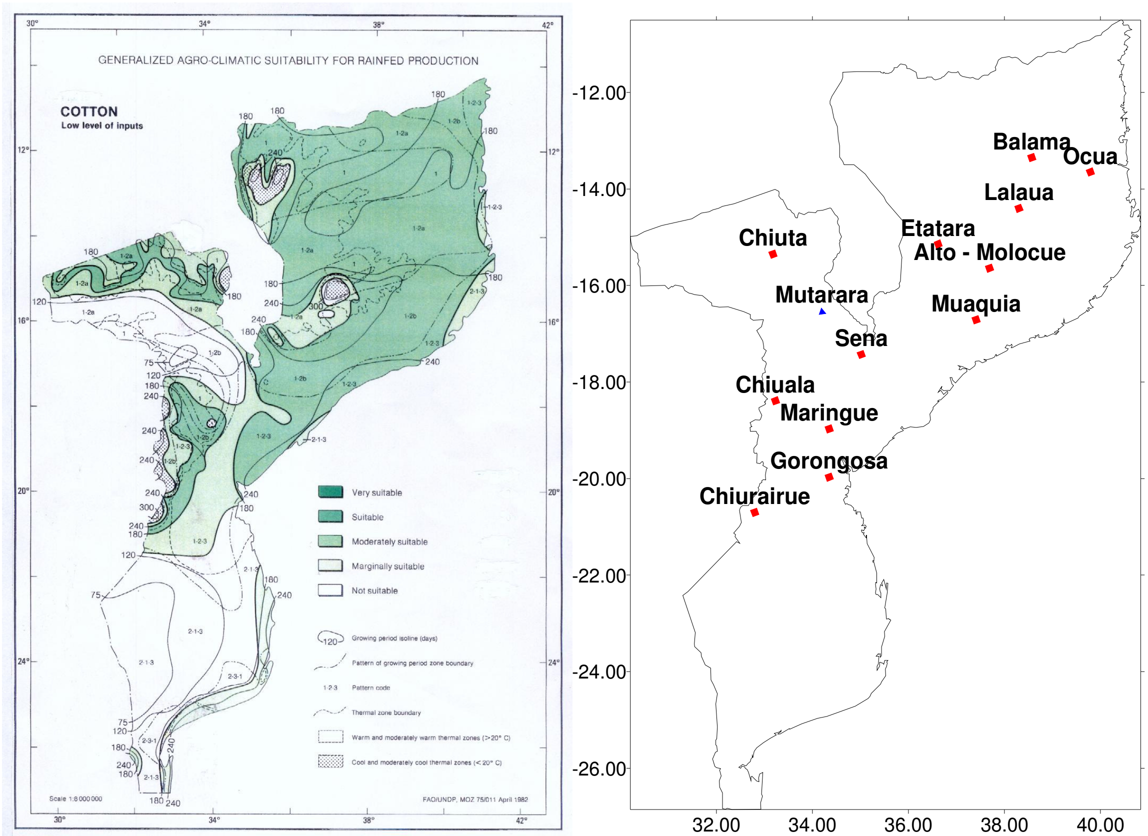

Figure 2: Agroclimatic suitability map for rainfed cotton production (left) and proposed locations for the 13 INAM-CI AWS (right). *Source CI & INAM*

3.1 Station equipment and specifications

Discussions with INAM revealed that there was no requirement to install similar AWS to what had been previously installed and that main requirements were that the equipment should be robust and maintainable by INAM staff. One option was to use the Casella system used in Malawi as this system has proved adequate for monitoring of the kind required in Mozambique. However, enquiries within South Africa revealed that the Agricultural Research Council (ARC) runs a network of similar stations within South Africa. These stations are based on the Campbell Scientific datalogger and use GSM/GPRS technology for transferring data. ARC has found the system to be robust and easy to maintain and they offer training in the AWS installation, maintenance and data capture. Given the cost of this weather station (see Appendix A for the quote), that ARC is close and potentially available for maintenance should the need arise this option was considered worth pursuing. Discussions are currently ongoing to determine if INAM should purchase the next model datalogger which would be required if more sensors were to be fitted, and potentially more robust sensors which will have a longer lifespan.

Given that the AWS would GSM/GPRS technology to transfer data it is essential that the proposed sites are covered by local network providers. The biggest two local networks are Mcel and Vodacom. Investigations by INAM suggest that of the 13 proposed sites, 10 are within range of a cellular network. The remaining 3 AWS would require manual download of the data which could present an additional layer of complexity which potential underwriters of contracts may not be prepared to accept e.g. quality control procedures would be delayed, which would increase delays before sensor drift or failures could be detected.

3.2 Maintenance

The envisioned arrangement would be that INAM personnel would be responsible for maintenance of the AWS. INAM would also run the network, including data capture, storage and quality control. Should anything go wrong that INAM were unable to fix, ARC may be contracted on an as needed basis to travel to Mozambique and help overcome any problems.

4. Options for further development

Given the existing station network, planned acquisition of AWS and the enthusiasm indicated by both INAM and CI, a more detailed feasibility study is advisable. There are several potential difficulties, not the least being missing data. However, without a clear geographical focus and access to the daily climate data it is impossible to say whether contract design may be feasible. In the context of the irrigation project, these details should be forthcoming soon allowing a clearer assessment.

By their very nature the new AWS are sited in locations where historical observations are spatially not very dense and this makes it more difficult to generate synthetic historical observations for their location. For this reason it is recommended that any potential focus area should be as close as possible to regions where existing synoptic or AgMet stations exist.

4.1 Engaging the insurance industry

It is not clear that the insurance industry in Mozambique is set up to deal with weather-index and agricultural production insurance in general. During the identification mission it was difficult to set up meetings with financial institutions, though initial contact with Global Alliance insurance (based in South Africa) indicated they were willing to consider new initiatives as long as the risk could be transferred to the international reinsurance market.

4.2 Identifying potential users and boundary partners

The most obvious interest has been from the CI with cotton farmers being the recipients of any insurance. Whilst this does not mean that there are not other potential users of weather-index insurance, it seems the most promising at the moment for the following reasons:

- There is a well-developed market for cotton;
- Cotton companies are already prepared to finance the installation of new AWS which represents a significant commitment;
- The CI could fulfil the role of an intermediate impartial entity that can be trusted by farmers.

4.3 Exploring contract design

Perhaps the biggest current unknown is the potential for designing an index that could accurately capture the effects of climate on cotton yields. As far as we are aware cotton has yet to be insured via this kind of financial instrument. Indexes are commonly based on the quantification of drought conditions and their effect on yield. This could be attempted via well known FAO relationships and crop coefficients, with yield data held by the CI used for calibration and testing. The success of this will depend on:

- The number of years of yield data for the region of interest;
- Whether any index is based on rainfall only or additionally needs temperature data and potentially humidity and wind speed data as well;
- Whether a crop model can simulate observed yields with reasonable accuracy.

Besides drought, tropical cyclones are known to affect cotton production though it is often unclear whether their destructive effects are due to high winds or rainfall, both of which can be highly localised. Both the compound nature of the hazard (making the hazard modelling difficult) and its very localised effects on yield (increasing the potential basis risk) make it unlikely that a weather-index contract can be designed to accommodate damages due to tropical cyclones.

Ultimately the potential for designing an index insurance scheme in Mozambique will depend on the location and available data. Therefore it is recommended that further focussed investigations be undertaken once locations for potential pilots have been clearly identified.

5. Appendix A – costing of weather stations

Below is an approximate costing for weather station equipment supplied by ARC of South Africa. All prices are in South African rand and do not include shipping charges to Mozambique or import duties. Some costs may not be needed e.g. hosting server which will be at INAM.

Description	Qty	Unit Price	Price	VAT	Amount
SC9C Modem cable for CR200,CR800 and CR1000	13	212.63	2764.19	386.9866	3151.1766
Cellular Sim Card with Data facility	13	301	3913	547.82	4460.82
Solar Panel module	13	779.67	10135.71	1418.9994	11554.7094
CV Regulator	13	196.66	2556.58	357.9212	2914.5012
Weather Resistant 12 x 14 inch enclosure	13	1976	25688	3596.32	29284.32
12VDC Sealed Rechargeable battery	13	132.64	1724.32	241.4048	1965.7248
Enclosure Mounting Structure	13	384.21	4994.73	699.2622	5693.9922
Vaisala HMP50 Temp/Humidity probe	13	2593.5	33715.5	4720.17	38435.67
6/10 Plate Radiation shield with offset bracket	13	1628.81	21174.53	2964.4342	24138.9642
Solar panel Mounting Structure	13	330.75	4299.75	601.965	4901.715
40 X 1500mm Galvanised standpipe	13	98.9	1285.7	179.998	1465.698
CR200 Data Logger	13	3951.99	51375.87	7192.6218	58568.4918
25X200mm Galvanised standpipe	13	8.88	115.44	16.1616	131.6016
25X500mm Galvanised standpipe	13	27.21	353.73	49.5222	403.2522
25 X 1000mm Galvanised standpipe	13	53.89	700.57	98.0798	798.6498
25X1500mm Galvanised standpipe	13	56.21	730.73	102.3022	833.0322
40 X 25 Galvanised MC reducing Tee	13	21.26	276.38	38.6932	315.0732
40 X 25 Galvanised MC reducing bush	13	8.2	106.6	14.924	121.524
25mm Galvanised MC Elbow	13	7.33	95.29	13.3406	108.6306
WS maintanance 5 year contract (per year) **	13	5000	65000	9100	74100
Travel costs for account of client	0	3.1	0	0	0
GSM/GPRS Dual band Modem with TCP/IP + 9pin db cab	13	1841.25	23936.25	3351.075	27287.325
Technician /hour (7hours/station for installation and setup)	91	300	27300	3822	31122
S&T foreign travel per day (R1500/day)	13	1500	19500	2730	22230
25X25mm galvanised MC Tee	13	12.5	162.5	22.75	185.25
GSM Blade Dual band Antenna-SMA Male with magnetic base	13	124.95	1624.35	227.409	1851.759
Model PYR-P Apogee SiliconPyranometer sensor	13	2063.91	26830.83	3756.3162	30587.1462
Model LEV Levelling fixture	13	323.53	4205.89	588.8246	4794.7146
03001 RM Young Wind Sentry WIND SET-speed+directi	13	5143.03	66859.39	9360.3146	76219.7046
TE 525-L Texas Electronic Rain Gauge 0.01 inch (0.254mm)	13	3649.05	47437.65	6641.271	54078.921
Once -off programming per station comms	13	500	6500	910	7410
hosting of server hardware and network min of 20 stations (per month)	12	1000	12000	1680	13680
Data structure and maintenance yearly cost per station	13	1200	15600	2184	17784
GPRS setup per station (once off)	13	150	1950	273	2223
Dailing software	1	5648	5648	790.72	6438.72
S&T foreign travel per day - 2 x Tutor (R1500/day/tutor)	20	1500	30000	4200	34200
Training - in service Weather Station maitenance and calibration training 10 days SA) S&T at own cost	10	1400	14000	1960	15960
			Total	**67,887.89**	**609,400.09**