

ANALYZING AREAL PRECIPITATION AT KEY BASINS IN COCHABAMBA USING SATELLITE-BASED PRECIPITATION

ANÁLISIS DE LA PRECIPITACIÓN AÉREA DE LAS CUENCAS CLAVE DE COCHABAMBA BASADO EN TECNOLOGÍA SATELITAL

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ABSTRACT

Monitoring spatial precipitation at high resolution is a crucial variable in semi-arid regions like Cochabamba city. However, limitations regarding the number, quality and uniform distribution of operating rain gauges inside the basin's area, lead us to examine data and combine it with satellite-based precipitation. These products' accuracy is increasing, but their evaluation needs validation before its usage in water balance. We focused in the five key basins that may provide water for agriculture and drinking purposes in metropolitan area of Cochabamba city (Cbba). A three level comparison was carried out, considering hourly and daily values of precipitation intensities measured at available stations, areas of influence and sub basins. Accumulated monthly values from Global Satellite Mapping of Precipitation (GSMaP) data correlate better than a comparison with Servicio Nacional de Meteorología e Hidrología SENAHMI's daily measures. The results showed spatial and temporal variability between GSMaP and SENAHMI stations. Actually, it is important to point out that in most cases; values estimated by GSMaP's became underestimated when compared against surface gauges. Hence, we propose a simple integration method of gauge-based and satellite-based precipitation data, using correction factors. We reached a 19 % improvement of areal precipitation for the rainy season 2015/2016, using correction factors obtained by correlating data from SENAMHI and GSMaP and evaluating the relative errors during previous rainy season 2014/2015. Subsequently, we plan to apply them as input to hydrological models to obtain river discharge values and determine whether the fulfilment of water demand in Cbba is possible. In future studies we plan to include the potential climate change scenarios and adjust precipitation variability according to elevation range which is 2500-3500 m.a.s.l. in this region. Results are expected to provide a higher resolution of precipitation, also produce more accurate water balance to support wise decisions over the water resources management in semi-arid regions.

RESUMEN

La medición de la precipitación espacialmente, en alta resolución, es una variable crucial en regiones semiáridas como la ciudad de Cochabamba. Sin embargo, las limitaciones en cuanto al número, la calidad y la distribución espacial de pluviómetros operando dentro del área de la cuenca, nos llevan a examinar los datos y combinarlos con las intensidades de precipitaciones estimadas desde satélites. La precisión de estos productos está aumentando, pero su evaluación necesita ser validada mediante la combinación de datos antes de su empleo en balances hídricos. En este artículo analizamos las cinco cuencas clave que pueden proporcionar agua para fines agrícolas y agua potable en el área metropolitana de la ciudad de Cochabamba. Se efectuó una comparación a tres niveles, valores puntuales en cada estación, promedios en áreas de influencia de las estaciones y dentro de áreas de las sub-cuencas, basada en intensidades de precipitaciones horarias y diarias. Se encontró que los valores mensuales acumulados entre GSMaP y SENAMHI se correlacionan mejor que una comparación de precipitaciones diarias. Los resultados muestran que existe variabilidad espacial y temporal de la precipitación entre GSMaP y las estaciones meteorológicas. Es importante señalar que en la mayoría de los casos, las intensidades estimadas por los productos de GSMaP han subestimado los valores medidos en tierra. Por lo tanto, se propone aquí un método simple para la combinación de los datos de precipitación estimados por satélite y medidos por pluviómetros. Se alcanzó una mejora del 19% en la correlación de datos entre SENAMHI y GSMaP evaluando los errores relativos de la temporada de lluvias 2014/2015 y aplicando factores de corrección para la siguiente época lluviosa 2015/2016. Posteriormente tenemos la intención de aplicar estos productos como datos de entrada a los modelos hidrológicos para obtener la descarga de los ríos y determinar si la demanda de agua en Cbba se puede satisfacer. Para estudios futuros tenemos la intención de incluir los escenarios de posibles cambios climáticos y considerar la variabilidad de la precipitación por la elevación que en la zona está en el rango 2500-3500 m.s.n.m. Los resultados esperados deberían proporcionar una mayor resolución de precipitación, producir un balance hídrico más preciso y contribuir a la toma de decisiones en la gestión de los recursos hídricos en regiones semiáridas.

Keywords: Cochabamba, Bolivia, GSMaP, Satellite-Based-Precipitation, Water Supply.

Palabras Clave: Cochabamba, Bolivia, GSMaP, Precipitación Estimada por Satélite, Suministro de Agua.

1. INTRODUCTION

Water resources management in Cochabamba city, Bolivia has been critically important ever since its foundation. At early times, there was good enough amount of quantity and quality of water available for human consumption, agriculture and greenery. After decades of exploiting these resources and because of the development of urban areas, population, and agriculture, demands regarding water availability have been increasing in the same proportion [1].

The municipal water works company, known as Servicio Municipal de Agua Potable y Alcantarillado, SEMAPA), only covers less than 60% of the total population. The remnant 40% gets their water supply from water trucks and wells at a price of 4.83\$ U.S. dollars per cubic meter while SEMAPA charges 0.9 \$US/m³. Cochabamba's water problem alleviated for almost two decades; nowadays, Misicuni is the amplest, reassuring water project, in which not only citizen's demands will be satisfied, but farmer's partial needs, may also be fulfilled in the near future. Misicuni's dam water system carries water from the basins in the mountains range surrounding the north valley to Cochabamba metropolitan area. Those volumes of water will be transported to Cochabamba's central valley through an already constructed tunnel. After several delays [2], the dam is expected to start operation in 2018.

The possibility at hand of obtaining accurate precipitation data sets provides information for diverse spatial and temporal application, flourishing in fruitful water resources management [4]. It's difficult for developing countries to obtain such precipitation data, because the number of rain gauges is not enough to cover purpose areas, besides the insufficient frequency of measurements can't capture intensive events like short storms [5]. To overcome this challenge, satellite-based precipitation measurement and downscaling methods have been broadly implemented. Satellite precipitation data was estimated by combining Microwave Radiometer (MWR) and Precipitation Radar (PR). MWR estimates two-dimensional rainfall intensity by large widths, directly measuring radiation strength of microwave from raindrops. PR estimates three dimensional rainfall intensity by measuring the active radio wave. Satellite-based precipitation measurement and downscaling methods has greatly enriched hydrology since the Tropical Rainfall Measuring Mission [6] launched in 1997. Since then, high-resolution satellite rainfall precipitation products evolved and boosted over the years, such as Global Satellite Mapping of Precipitation (GSMaP) products [7], the TRMM Multi satellite Precipitation Analysis (TMPA) product 3B42 [8] and the Climate Prediction Center's (CPC) Morphing Technique [9]. These products have spatial (0.25° or higher) and temporal (3 hours or shorter) high resolution, together with data covering most of the globe. Performance analogies of these products nourish our understanding of the advantages, disadvantages and achievements; helping us recognize the purpose and future use of these tools [4].

Previous studies show the application of many released satellite rainfall products. These products were tested and evaluated in diverse areas by comparing their rain gauges' performance [10]. GSMaP products gained popularity among researchers [11]. The GSMaP project initiated in November 2002 with the ambition of developing an advanced microwave radiometer algorithm and produce high-resolution global precipitation maps. The data has a 0.1° grid spatial resolution and an hourly temporal resolution [12]. GSMaP started as a descendant of the Tropical Rainfall Measuring Mission (TRMM), which aimed to achieve for higher, finer, and more accurate results than TRMM [13]. The GSMaP product with the newly added global gauge network was renamed to gauge-adjusted GSMaP (G_Gauge). This product adjusts GSMaP Moving Vector with Kalman Filter (G_MVK) with CPC unified gauge-based analysis of global daily precipitation (CPC Gauge) products to obtain a much higher accuracy results at an hourly scale [7]. The CPC Gauge is a daily precipitation dataset with a 0.5° lat-long grid over the global domain from gauge reports at over 30,000 stations [14].

The previous versions of G_MVK have been evaluated in China's southern regions [11]. Both studies show surpassing attainment during wet seasons compared with dry ones, reported aspersion of rain intensities especially over mountainous regions. However, the latest version of GSMaP's product, labeled G_Gauge, has yet to be tested at different widths and amplitudes [15].

The latest GSMaP product is based on the Global Precipitation Mission (GPM) so-called (GPM-GSMaP). GPM core satellite was launched in March 2014. The current version still has many bugs carried that is treated in the interpretation and validation. Satisfying GSMaP precipitation estimates in regions show positive scores; on the contrary negative results will be over less dense gauge regions. G_Gauge does not always show satisfactory results [16] specially during snowfalls or during high variability of elevation [17].

We attempt to evaluate the spatial precipitation performance of the latest version of GPM-GSMaP in Cochabamba city, a semi-arid region of Bolivia. The zone that implies the most difficult analysis might be the north area, which lacks enough data for the comparative analysis between G_Gauge and local rain gauge network. The ultimate goal is to provide enough data to achieve water balance in the main basins of Cochabamba metropolitan region.

2. STUDY AREA

Cochabamba city is located inside the Rocha river catchment, with a total extension of 3,655 km², starting in the Tunari's mountain range, crossing Tiraque's municipality and setting in the borders of Arque River. Inside Rocha's Basin 24 out of 47 Cochabamba's municipalities can be found. According to Bolivia's 2012 census 74.56% of the total department population live in the main city, around 1,310,908 inhabitants. Thirteen Municipalities' 100% surface area happens to be inside the main basin, whereas 11 are found to be partially in. The area of study is built of 5 main sub-basins named: Valle Alto, Valle Central, Valle Bajo and Valle de Sacaba, thus establishing the main Rocha basin and Misicuni's sub basin as seen in Figure 1.

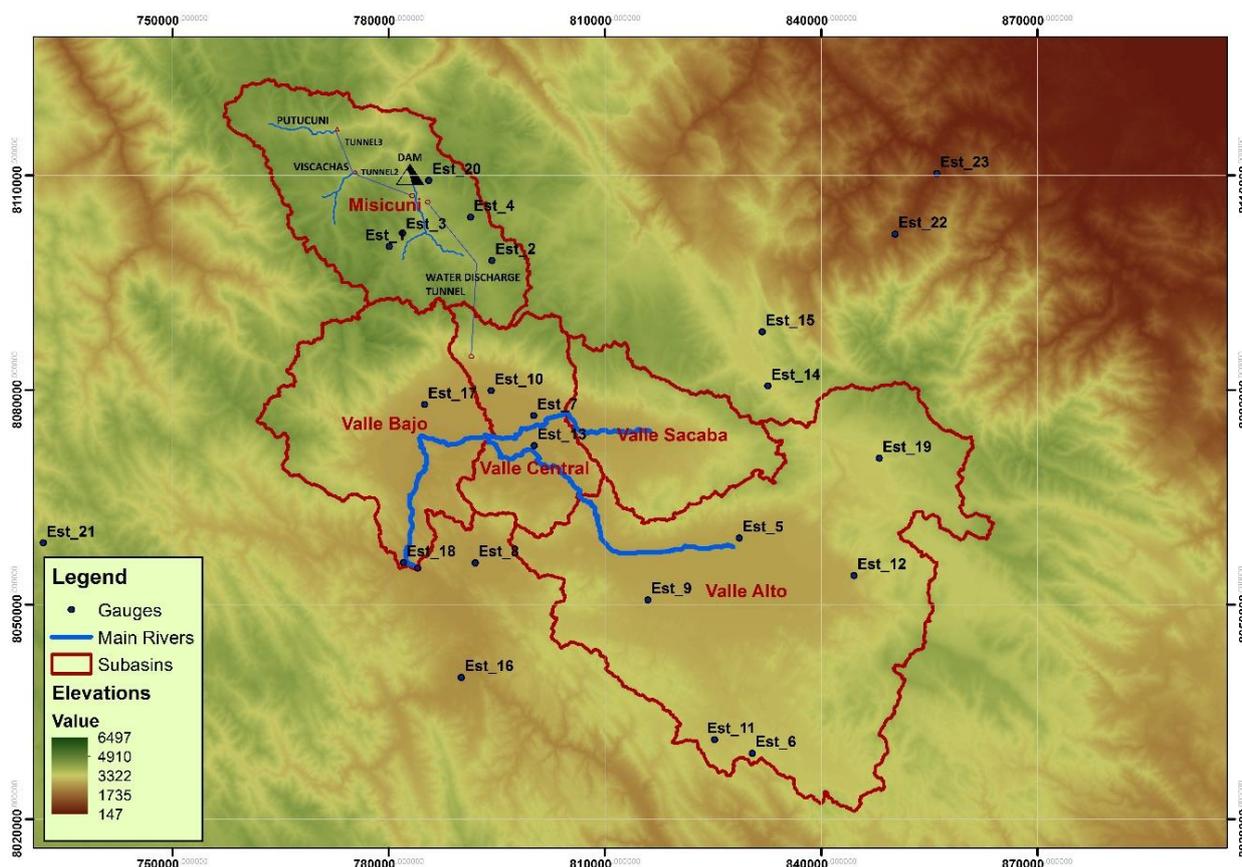


Figure 1 - DEM and delimitation of Sub Basins.

Rocha River Basin is included in the Andean region, which belongs to Rio Grande Basin and the eco-region of Andean dry forest. Its climate vegetation consists of micro forests to deciduous meso-forest, micro foliates and presenting partially abundant spinous cactuses. Within the diversity of flora of the valley highlights, the presence of Molle, Eucalyptus, Pine, Carob, Sauce, Ceibo, Acacias and Queuña highlands. More over there is great diversity of herbs that are used for medical purposes and a variety of fruit trees.

Wildlife is affected by the growing population and fast paced growing communities' density and deforestation throughout the area, causing loss of habitat and excess hunting leads to loss of gradual biodiversity. Within biodiversity and basin's limits, protected areas where established, but there is a constant risk that threatens their future ecosystem. Important natural national parks and water reservoirs are located inside the region such as the Tunari National Park, Lake Alalay and Lake Coña Coña.

Annual water precipitation for the 5 main sub-basins goes as follows: Valle Alto 552 mm which is the lowest quantity of water a year, but representing 56.16%, Valle Central 600 mm a year and its surface representing 7.95%, Valle Bajo 646 mm a year and representing 23.84% and Valle de Sacaba with a total of 622 mm, representing 12% of the total surface area. High valley's runoff waters will feed dam "Angostura," then once stocked in the reservoir, water will be discharged and distributed through the Valle Alto, Valle Central and Valle Bajo, handing over water for agricultural use and boosting economic growth. Thus, changing the natural environment, its biophysical characteristics and socioeconomically level. Misicuni basin connects the Rocha basin through a 19.45 km water discharge tunnel, and additional two supplementary tunnels will be constructed to capture water from Viscachas and Putucuni sub-basins [3].

Figure 1 also shows DEM elevation and a geographical relation between the four main Rio Rocha sub-basins and Misicuni's basin, an abduction system and tunnel are also displayed.

3. METHODOLOGY

Obtaining areal precipitation means interpolation of rain gauge point data to be compared against gridded satellite-based precipitation data was performed by analyzing levels to determine values of accuracy between GSMaP and SENAMHI rain stations (SENAHMI values where taken as the reference).

3.1 Data Preparation

For the purpose of this study, data were compiled and checked. Stations near and inside the study area were selected. Each station was given a code, adding up to 23 stations. Each station was changed and organized in *.CSV files. Each file was given the number of station and inside the file, year, month, day and daily precipitation intensities were separated by commas.

3.2 Rain Gauge

The rain gauge data was obtained from the National Service of Meteorology and Hydrology of Bolivia (SENAMHI). There are 34 gauge stations which observe rainfall data directly within the study zone.

A total of 10 gauge stations were incomplete for the first period of comparison, the second period, or both. Missing data were filled out according to neighboring values.

From the remaining 24 stations, 20 had fully rainfall data for every day of every month and needed no fill. The other four gauges belong to the Misicuni's basin area and were close to each other, but were not possible to get data from January 2016 to March 2016 due to data still being processed for public access. Because of the lack of gauges in the Misicuni's basin area, it was not possible to eliminate these stations and had to be filled. The data fill was made from the rainfall data of the "Misicuni AUT" gauge (also known as "Aguadas" gauge), which recorded data until March 2016. The linear correlation coefficient method was used to fill missing data [18] as shown in the Figure 2.

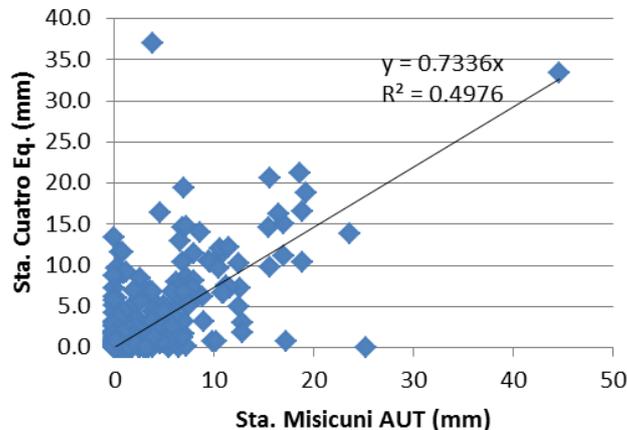


Figure 2 – Quality control at Cuatro Esquinas Station.

3.3 Global Satellite Mapping of Precipitation (GSMaP)

Raw data was downloaded from (www.gportal.jaxa.jp) G portal in .h5 format y was processed and turned into ASCII files, correctly geo-referenced, using Python, and Fortran.

Once data precipitation archives were obtained, necessary tools were needed to define the layer with all the points, resolution and time zone in the area of study. Once projection is defined, data must be selected and processed once again to obtain daily and monthly precipitation.

3.4 Evaluation of GSMaP

The subsequent aim for obtaining distributed satellite rainfall data was to compare them promptly with the data provided by stations on land surface using SENAMHI's network. As a first level of evaluation daily intensities estimated by GSMaP, corresponding to the location of each station were prepared and calculated the Pearson correlation coefficient $r_{x,y}$ for daily and monthly data between databases.

$$r_{x,y} = \frac{n \sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n \sum x_i^2 - (\sum x_i)^2} \sqrt{n \sum y_i^2 - (\sum y_i)^2}} \quad (1)$$

where n : Number of values, x_i : SENAMHI's values, y_i : GSMaP's values.

The second level of comparison is based on influence area for each SENAMHI's stations, which were prepared by implementing Thiessen polygons in the study area. Based on these polygons the values given by GPSMAP, within each of these were averaged to subsequently compare them as in the first comparison level, tabulating these daily values given by both the average GSMaP in each polygon and like SENAMHI, each one corresponding to each polygon station. With the extracted data we proceeded to calculate through Pearson's correlation coefficient between both daily and monthly.

For the third level of comparison, the values given by GSMaP within each sub-basin in the study area were compared to those worked with data from interpolated SENAMHI's stations. Each station with a certain area of influence within each sub averaged basin, this provided a correlative value to the area of influence, percentage number for the average values within each sub-basin. Hence, the results to calculate the Pearson correlation coefficient of daily and monthly of both sets of data were tabulated.

3.5 Correcting factors

Noting the correlation coefficient in rainy season between monthly data from SENAMHI and GPSMAP (GE_i , GSM_i), a linear correction factor related to the relative error calculated in the rainy season is analyzed to adjust future data as the next season arises.

$$E.R._i [\%] = \frac{GE_i - GSM_i}{GE_i} \times 100 \quad (2)$$

where:

$E.R._i$: Relative Error for i position
 GE_i : SENAMHI's precipitation value for i position
 GSM_i : GSMaP's precipitation value for i position

This relative error is applied as a multiplier to the monthly data GPSMAP of the next rainy season hoping to reduce the relative error in cases where an underestimation or overestimation of GPSMAP regarding SENAMHI data occurs.

If:

$$E.R._i [\%] \times E.R._{i+1} [\%] > 0 \rightarrow GSM_{i+1} = \frac{E.R._i [\%]}{100} \times GSM_i \quad (3)$$

where:

$E.R._{i+1}$: Relative Error for the same position position in the next season
 GSM_{i+1} : GSMaP's precipitation value for i position in the next season

Otherwise, it is advisable to keep the original value of GPSMAP as there is no direct relationship between the two months.

4. RESULTS

In this section, major results will be explained. First, we need to emphasize the importance regarding density of SENAMHI stations when compared to GSMaP 0.1-degree grid size. If the distribution is not uniform, then the level of comparison decreases. The employed stations in this study can be seen in Figure 1, and they were organized by number which may influence the key sub-basin as shown in Table 1.

The first comparison level (i.e. at each rain gauge station) includes daily and monthly data from SENAMHI and the corresponding GSMaP's grid. The results can be seen in the GRID columns of Table 2. Overall, daily correlation coefficient values are lower than monthly basis. The highest and lowest correlation coefficient values can easily be distinguished in Table 2 following the color range. It varies from red to green, green having the highest correlation and red having an extremely different precipitation values.

TABLE 1 SUB BASIN'S STATIONS DENSITY

Sub Basins	Code	N° Stations inside	N° Stations Considered	Area (km ²)	Density (# st./ km ²)
Valle Bajo	4	2	7	871.39	0.0023
Valle Central	2	3	5	290.77	0.0103
Valle Alto	3	6	7	2053.07	0.0029
Valle Sacaba	1	0	5	440.60	0
Misicuni	5	5	5	795.57	0.0063
TOTAL				4451.40	

TABLE 2 - FIRST LEVEL CORRELATIVE COEFFICIENT COMPARISON

STATION	PEARSON CORRELATION COEFFICIENT				ELEVATION M.A.S.L.
	DAILY		MONTHLY		
	GRID	THIESSEN	GRID	THIESSEN	
Templo	0.276	0.323	0.796	0.8059	4265
4 Esquinas	0.212	0.2414	0.698	0.7925	4206
Sunjani	0.237	0.2464	0.811	0.8169	4371
Aguadas	0.278	0.2927	0.881	0.925	4208
San Benito	0.057	0.0563	0.741	0.7421	2700
Sacabamba	0.025	0.0345	0.158	0.175	3149
Sarco	0.196	0.2071	0.866	0.8748	2577
Santivanez	0.048	0.0495	0.559	0.5616	2537
Tarata	0.06	0.0684	0.688	0.6963	2750
La violeta	0.27	0.2828	0.803	0.8146	2607
Anzaldo	0.034	0.034	0.379	0.3897	3034
Arani	0.058	0.0728	0.751	0.7657	2836
CbbaAirport	0.147	0.1642	0.919	0.9194	2561
Colomi	0.037	0.0403	0.791	0.7932	3284
Cayarani	0.045	0.051	0.547	0.5793	3352
Capinota	0.068	0.0715	0.673	0.6521	2393
Pairumani	0.087	0.0861	0.791	0.7428	2604
Parotani	0.112	0.1121	0.671	0.6364	2475
Tiraque	0.036	0.0461	0.739	0.7286	3292
Sivingani	0.13	0.1394	0.574	0.6285	4157
Chaupisuyo	0.114	0.1716	0.568	0.6231	3768
S. J. Barro Negro	0.018	0.0154	0.277	0.2437	1269
Chocolatal	0.002	0.0024	0.242	0.2679	672

Detailed monthly comparison graphs at selected SENAMHI stations are showed in Figure 3. The best correlation was found at Cochabamba airport with 0.92 while the worst was found at Chocolatal station with 0.24 as seen in panels A and B of Figure 3. The monthly hyetographs can be seen in panels C and D of same Figure. Very good agreement is depicted at Cochabamba airport during the two rainy seasons.

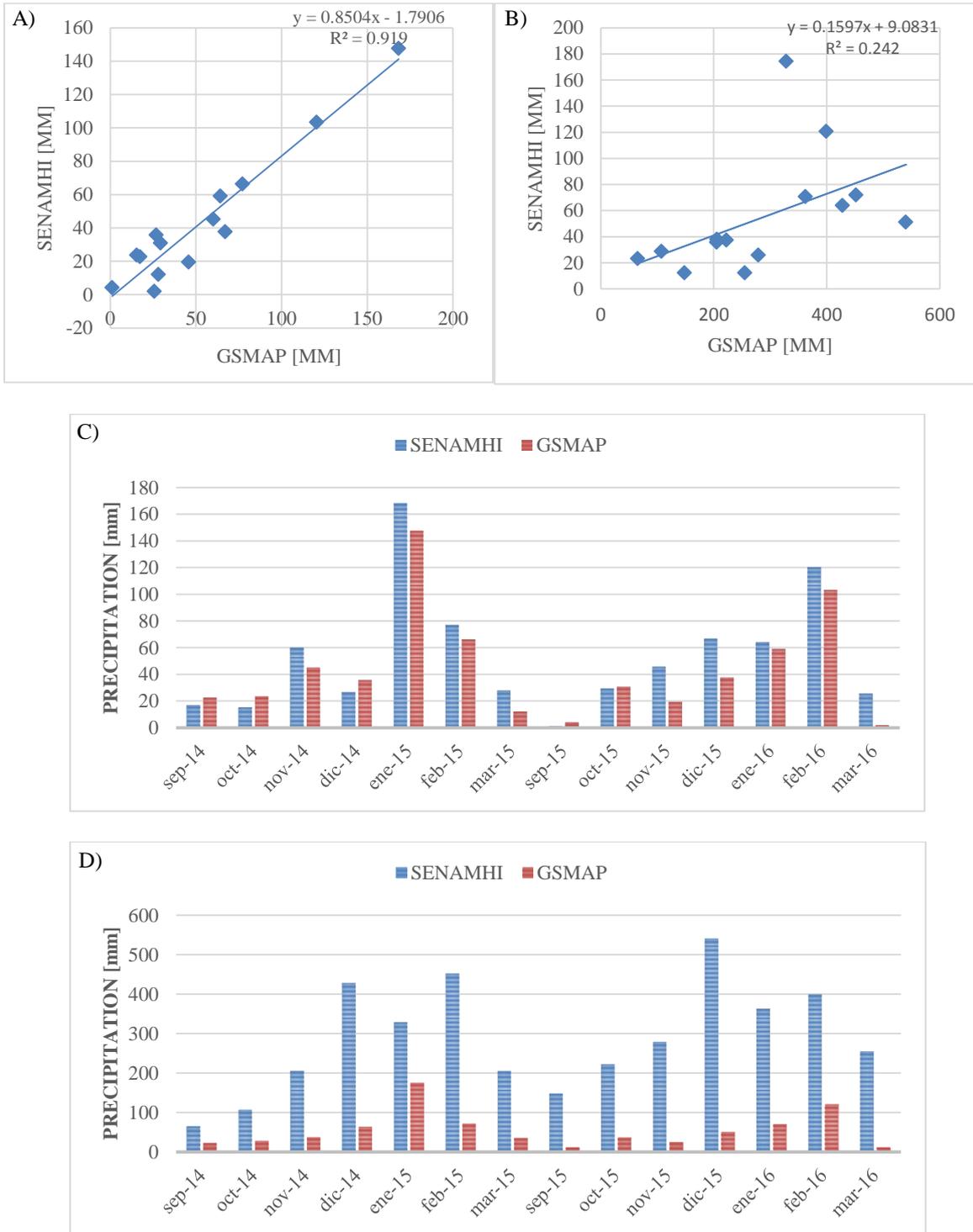


Figure 3 – First level of evaluation at best and worst stations. Scatterplots at Cochabamba Airport (panel A) and Chocolatal station (panel B). Monthly hyetographs at Cochabamba Airport (panel C) and Chocolatal station (panel D).

The second level of comparison took place by extending SENAMHI's daily data within their area of influence using Thiessen Polygons and GSMaP's pixel values turned in same areas as seen in Figure 4.

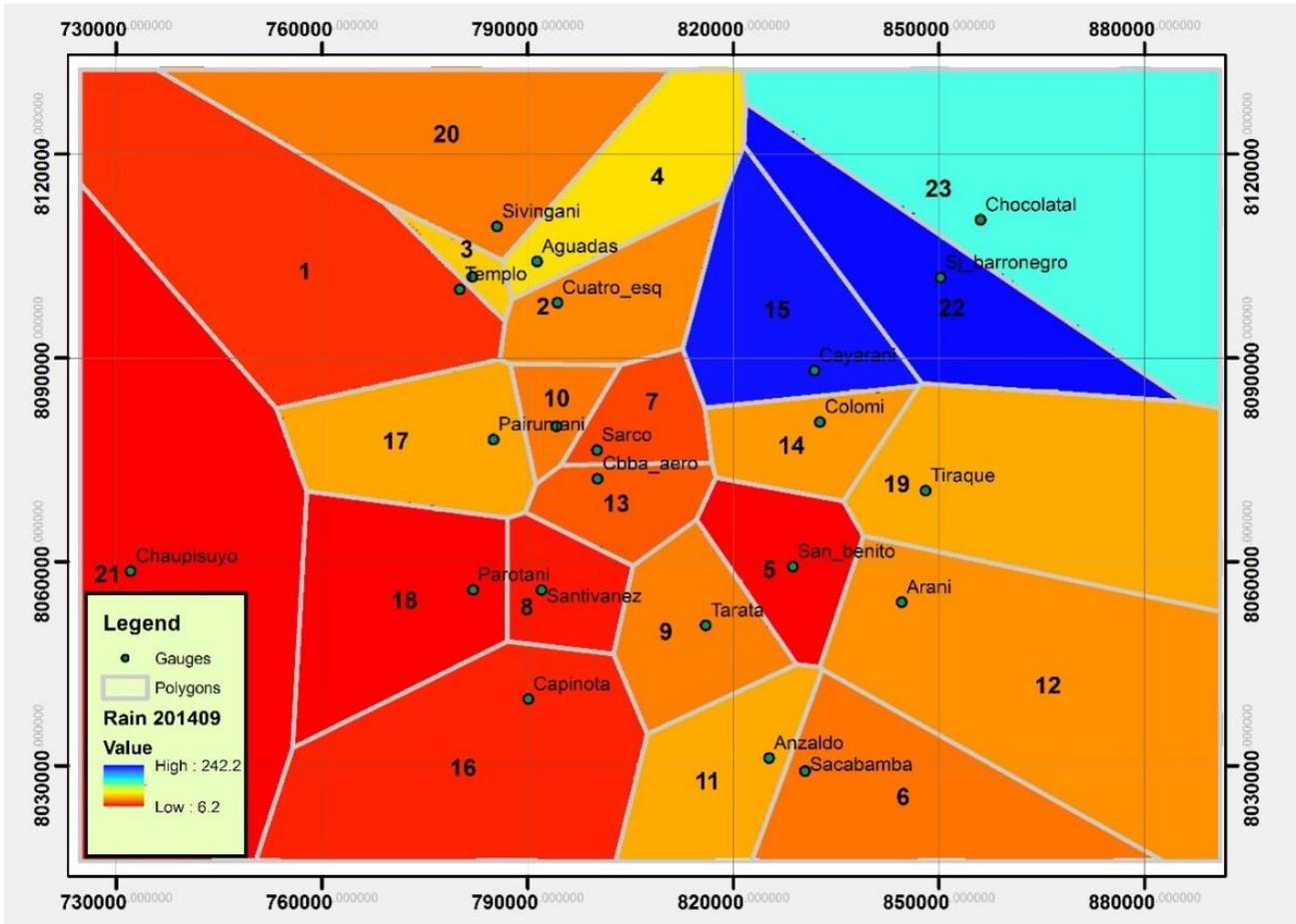
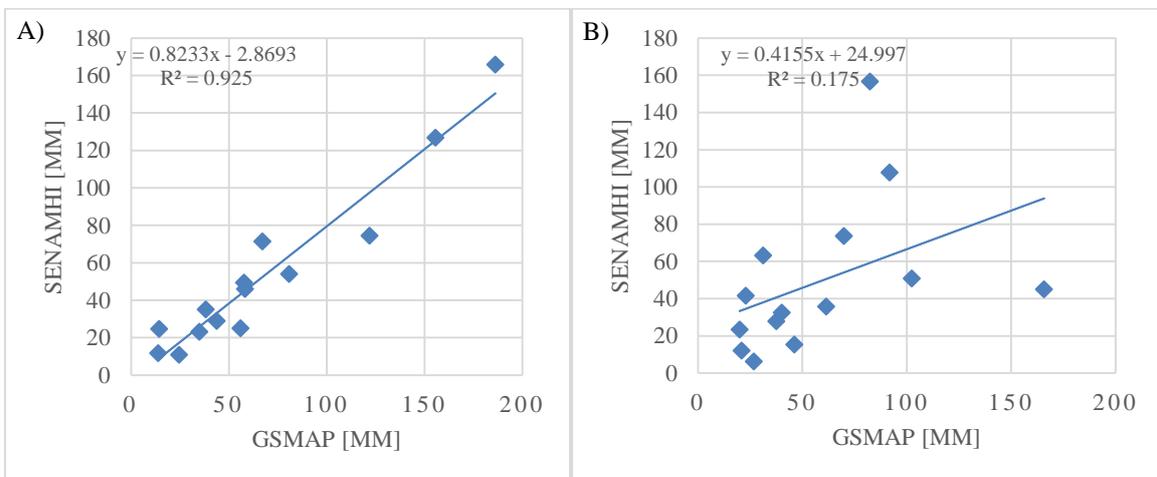


Figure 4 – Second level of comparison, areas of influence per rain gauge station using Thiessen polygons with monthly precipitation in September 2014.

Inside the polygons a total average value is compared both data sets as seen in columns “Thiessen” of Table 2. The intensities are constant within each polygon. The best correlation was found within Aguadas’s polygon(station 4) reaching 0.925 while the worst was found at Sacabamba’s polygon with 0.175 as seen in panels A and B of Figure 5. The monthly hyetographs can also be seen in panels C and D of Figure 5. It is important to point out that correlation coefficient values once more increases at monthly analysis.



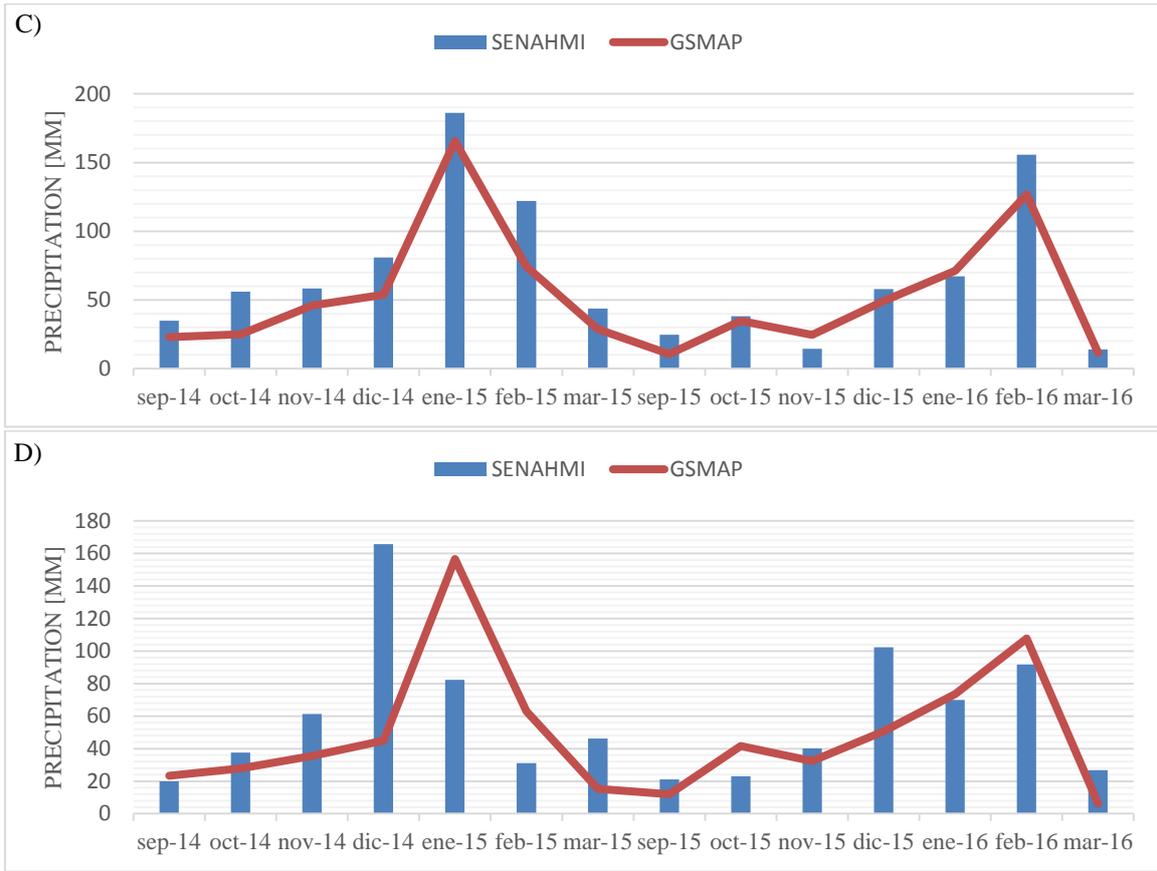


Figure 5 – Second level of comparison temporal analysis within Thiessen polygons. Scatterplots of average intensities for Aguadas (panel A) and Sacabamba stations (panel B) for best and worst cases respectively. Monthly average hyetographs at Aguadas (panel C) and Sacabamba stations (panel D).

The spatial distribution of precipitation of SENAMHI and GSMaP can be seen for September 2014 (best) in Figure 6 and March 2015(worst) in Figure 7.

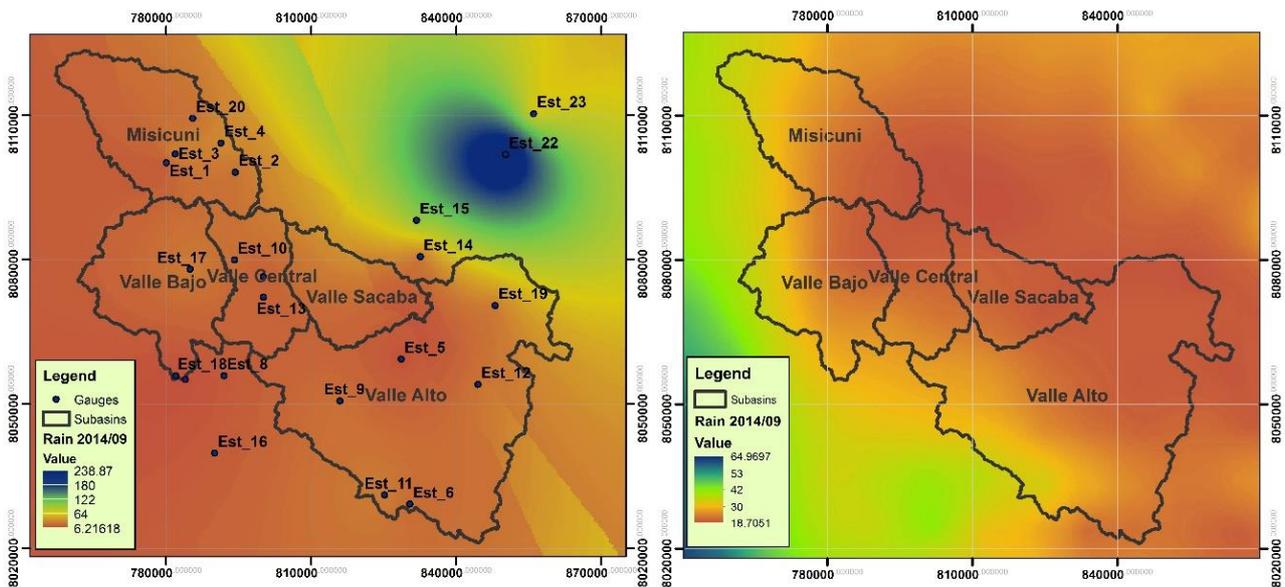


Figure 6 - Second level of comparison using Thiessen polygons, rain gauge stations(left) and GSMaP(right) precipitation distribution for the worst correlation in September 2014. Intensities were smoothed for visualization purposes.

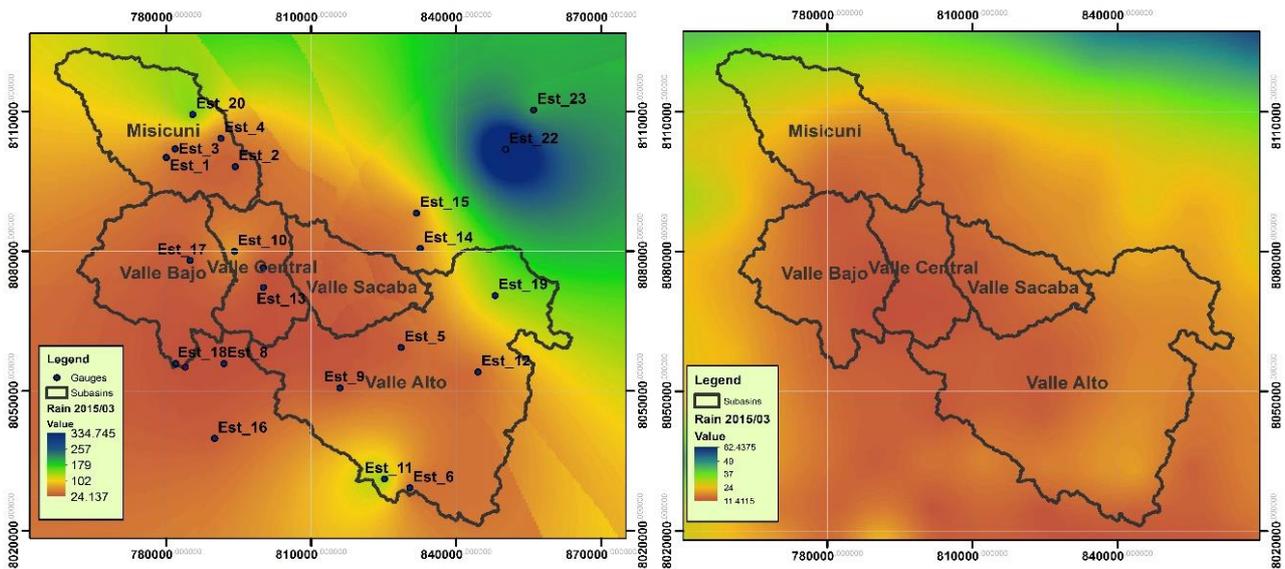
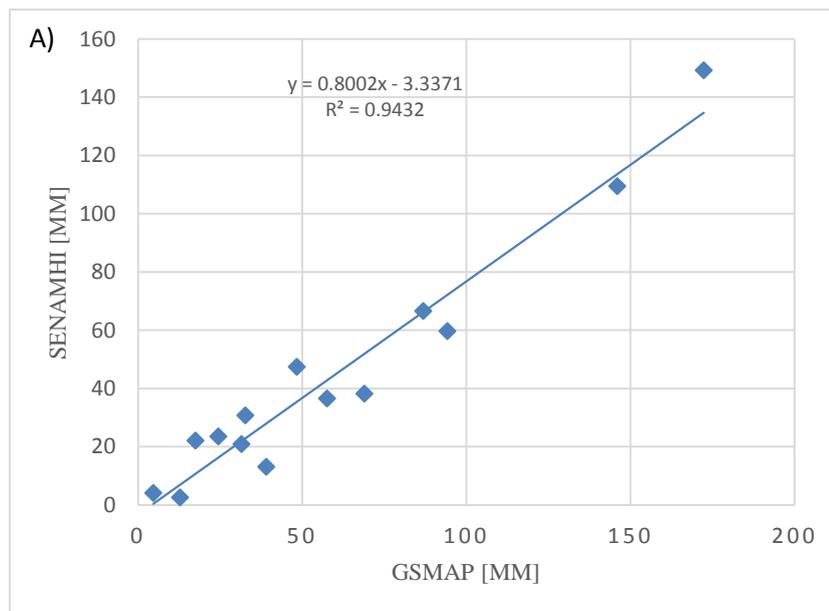


Figure 7 - Second level of comparison using Thiessen polygons, rain gauge stations(left) and GSMaP(right) precipitation distribution for the worst correlation in March 2015. Intensities were smoothened for visualization purposes.

Note that the intensities were smoothened only for visual comparison purposes. Actual constant intensities within each polygon were used for the analysis. Rain gauge’s intensities (left panels of Figures 6 and 7) seem very much influenced by high intensities recorded at northeastern stations like Barronegro (est_22). Even though it can be clearly seen that GSMaP underestimates the precipitation intensities, GSMaP can show the spatial distribution.

The third level of comparison was performed at key sub basin areas. Rain gauge’s intensities within each sub basin area were averaged to obtain a representative value. Then, GSMaP’s pixel values were processed and averaged according to the size and shape of these sub-basins, obtaining a unique value for each one. Results between them show even higher correlation coefficient than level one and two as seen in Figure 8 for Valle central basin. The correlation reaches 0.943 at upper panel and very close agreement for monthly hietograph from September 2014 until March 2016 at lower panel of Figure 8A-B.



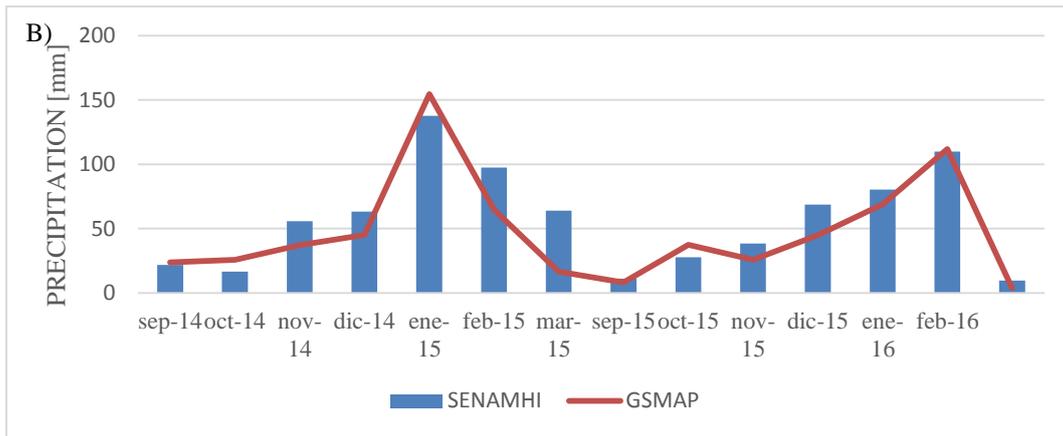
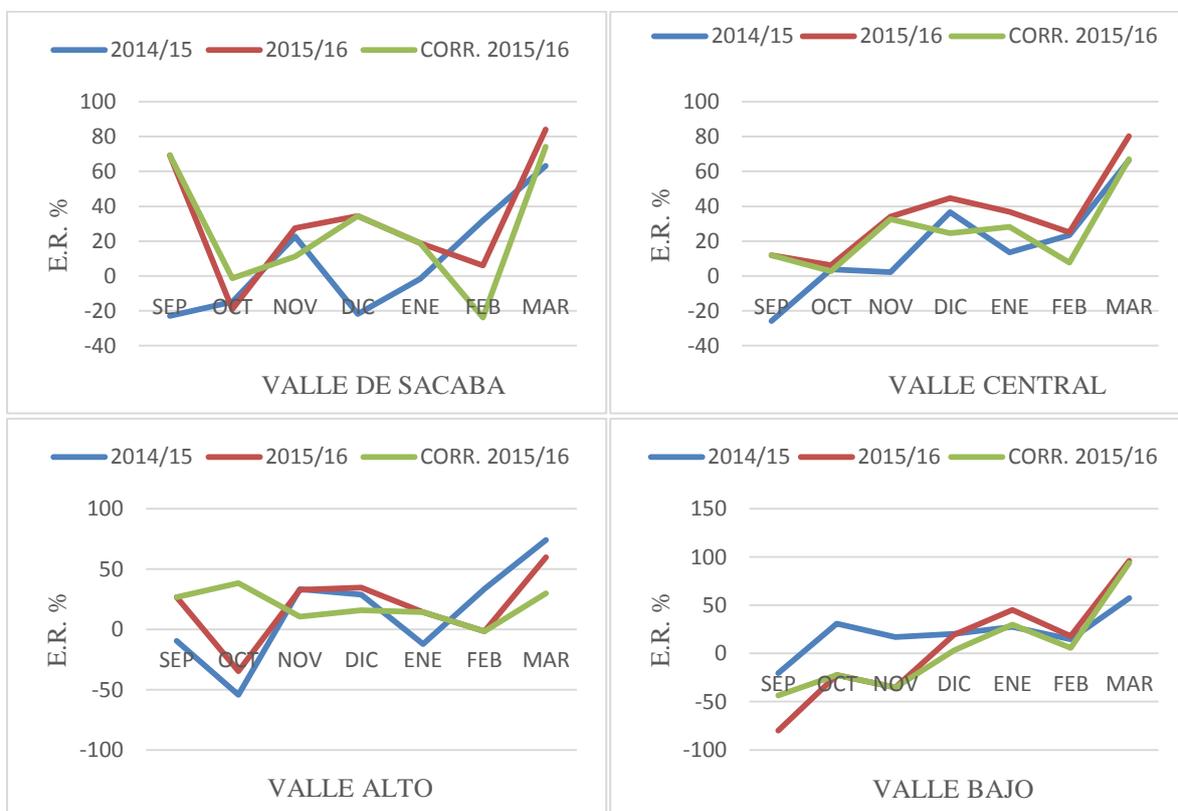


Figure 8 – Third level of comparison. Correlative coefficient and precipitation data for “Valle Central” sub basin.

Once the gap between rain gauge network and GSMaP was identified, we propose a correction factors for GSMaP estimations. First, the relative error at each sub-basin was calculated using Equation 2. Then, a correlation coefficient was developed and projected over the next rainy season. According to this result, we compared SENAMHI and GSMaP for the projected season. A correction coefficient is found in the first rain season to correct underestimation and overestimation from SENAMHI’s results. Analyzing 2014/15 and 2015/16 season’s relative error, a correction coefficient is applied to the last season using Equation 3. The relative errors in 2014/15 and 2015/16 are portrayed in blue and red colors respectively as seen in Figure 9. Five panels are displayed one per studied sub-basin. In green color the relative errors can be seen after applying the correction factors.

As for the correction of the spatial distribution of precipitation, the worst monthly correlation between rain gauge network and GSMaP was taken, as seen in Figure 10 in March 2015. The correction factors per sub-basin were distributed to all grids per data set. In this way, a new adjusted GSMaP precipitation distribution was obtained as shown in Figure 11. The underestimated values, clearly seen for Misicuni and Valle Alto were successfully corrected for March 2016 as seen in left panel of Figure 11.



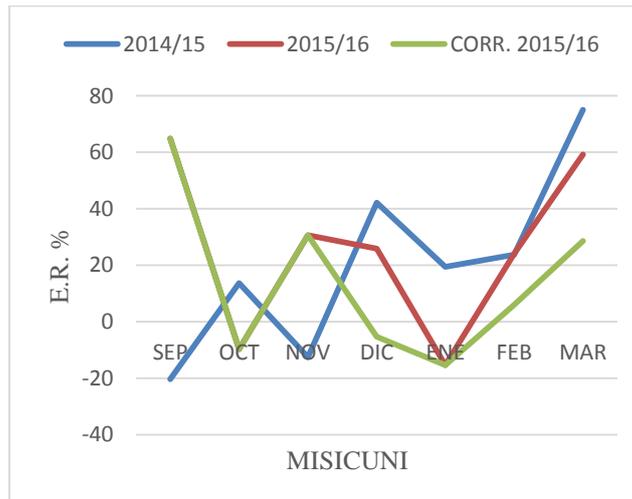


Figure 9 – Evaluation of GSMaP at sub-basin level. Relative Errors at each Sub Basin during rainy seasons

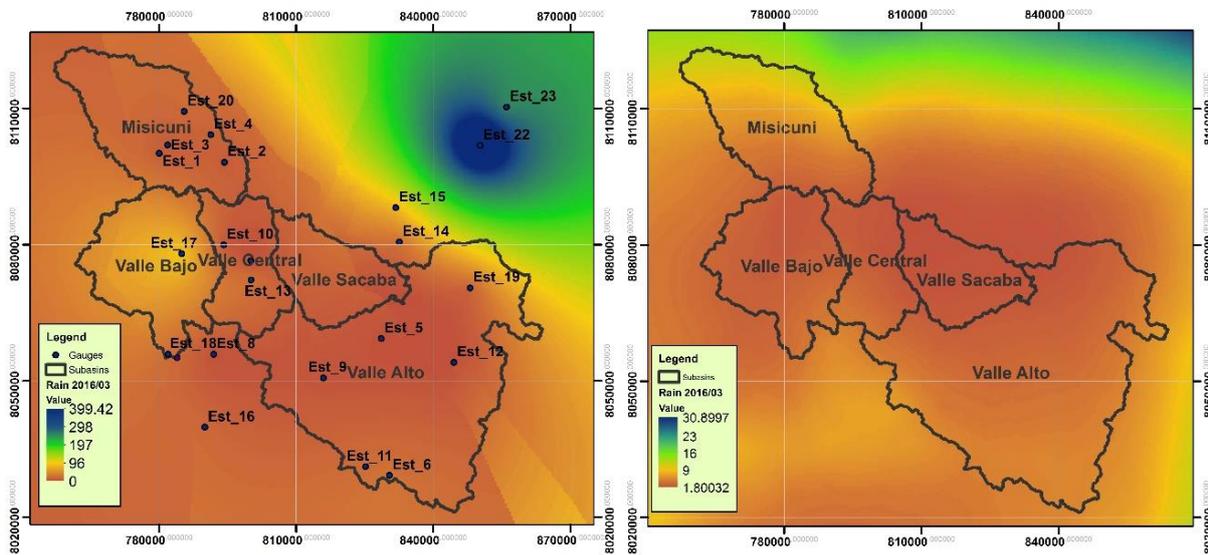


Figure 10 - Spatial precipitation distribution of rain gauge network(left) and GSMaP(right) in March 2015.

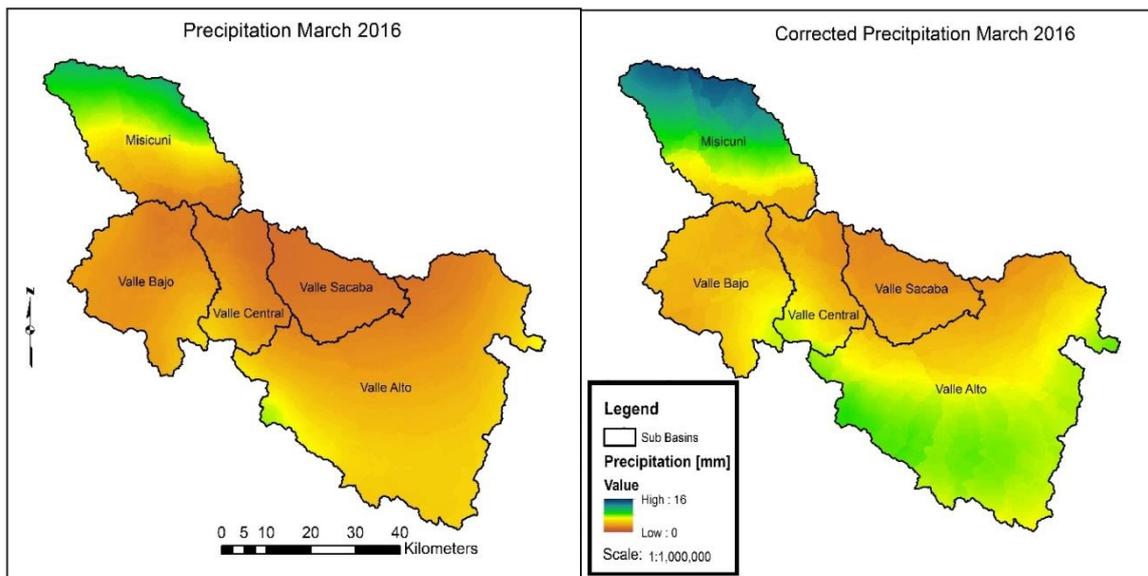


Figure 11 - GSMaP precipitation distribution without correction (left) and corrected precipitation(right) for March 2016 using the proposed correction factors.

5. CONCLUSION

SENAMHI's quality data shows questionable results for precipitation, for this reason it is important to perform a quality control check over station's data. Some of the measurements were found inconsistent. Then, identifying errors in the location of weather stations is essential for exact results. Cochabamba airport station manifest greater accurate results, although is not entirely run by SENAMHI, weather data quality is better than other stations. This can be explained by the station's usefulness and value alike Cochabamba Airport station that requires knowing weather condition at all times, comparing to stations in the mountain that only serves for the sole purpose of measuring.

Another aspect to be considered is the fact that GSMaP's gauge data is calibrated with CPC global rain gauge network and has a higher Pearson correlation coefficient value when analyzed monthly, unlike SENAMHI's daily data. For this reason, monthly data happens to have a greater correlation coefficient than those of the daily. Thus, it is not appropriate to perform daily analysis, but monthly results and comparison among them show greater promise.

GSMaP's spatial precipitation distribution was mainly underestimated and through our proposed correction method, we managed to decrease this gap, reaching 19 % correlation improvement from SENAMHI and GSMaP. Future corrections should include a longer precipitation period and an elevation data correction.

For more coherent results, it is required to include more satellite products such as IMERGE, CMORPH and so on. To improve the out coming results, it is advisable to include more data from previous years. In addition, it is important to point out the rainy season changes each year and the correction here was considered by month, not by season. It means we assume that similar intensities precipitate in same months that not always be the case. Rainy seasons may start earlier or later than previous ones, not to mention the duration of the rainy season. In short, the simple correction approach employed and specified in methodology for GSMaP may include longer periods with variability of topography, temperature, wind direction and speed, solar radiation, and for different ecological regions.

A high resolution of spatial precipitation is more likely to produce a more accurate water balance to support wise decisions over the water resources management in semi-arid regions.

6. DISCUSSION & OUTLOOK

Interpolation using PRISM method by ANUSPLIN software shaped in Hijmas's work on high-resolution interpolated climate surfaces for global land areas. Corrections should be carried out by latitude, longitude, temperature and elevation. If any other data is available should be applied to these, such as wind speed, solar radiation, etc. [19]. Whereas, corrections made for this investigation were on a monthly scale, relative errors are added as a multiplier to the monthly data for GPSMaP's next rainy season, reducing relative errors in cases where an underestimation or overestimation occurs regarding SENAMHI's data. This includes that SENAMHI's quality information requires a more extract quality control to avoid astray results and data received should be compared with other stations nearby.

This study was carried to develop an understanding of precipitation behavior in the key basins of Cochabamba. It is important to increase the outreach of the study. For example, a water balance is required for all the sub basins to estimate water volume. Water still available inside the Rocha basin should be quantified, examined and contrasted with demands regarding available drinking water, agricultural irrigation water and industrial water. Thus, once water offer is compared with water demands, the outcome value will determine if Misticuni's water and Rocha's basin water is enough quench water needs inside Cochabamba City's metropolitan area, if that weren't the case new projects are required. For example, the Northeast region of the studied domain depicts higher precipitation intensities than the five analyzed sub-basins. Thus, sound projects in water management to fulfill demand in Cochabamba metropolitan city should be studied.

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