Soil Moisture Retrieval from MODIS and AMSRE Satellite Data A Case Study of Sindh Province, Pakistan

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Abstract: Sindh province has diverse agro-climatological regions ranging from irrigated agricultural belt in the middle and desert to the east and bare hilly ranges on the west. Climate of the province is semi-arid with low annual precipitation of around 200mm. Agriculture and agribusiness is the main source of livelihood for majority in the province. Soil moisture study is an important parameter in agriculture, hydrology and hydrometeorology for studies related to sustainable development of agriculture and agribusiness in the province. In agriculture, soil moisture is used to study evapotranspiration, droughts, irrigation scheduling, and crop yield forecasting. It is also important for the environmental studies like subsequent precipitation patterns, temperature change and water quality. Soil moisture plays an important role in hydrology e.g., flood control, soil erosion and slope failure, reservoir management, geotechnical engineering and runoff generation. Due to synoptic coverage and high temporal resolution satellite remote sensing is ideal for instantaneous measurement of soil moisture content and its spatial and temporal behavior. In this study soil moisture at province level has been mapped through Advanced Microwave Scanning Radiometer (AMSR-E) and Moderate Resolution Imaging Spector Radiometer (MODIS) for the years 2007 and 2010. As 2007 was as normal year while 2010 was a wet year due to heavy rainfall and flood in the province, both the years have been selected to study soil moisture anomalies in normal and wet seasons. The results of MODIS derived soil moisture is in moderate agreement with AMSR-E soil moisture product proving the effectiveness of high resolution products in optical range.

Keywords: Soil Moisture, MODIS, AMSR-E, Agriculture, Remote Sensing, Hydrology.

I. INTRODUCTION

Soil moisture is the quantity of water in the Soil. Volumetric or gravimetric measurements are used to study the soil moisture for a particular area, and a soil temperature sensor is generally required for calibration to get an accurate measurement. Soil moisture has its important role in hydrology such as flood control, soil erosion and slope failure, reservoir management, geotechnical engineering, runoff generation [1].

In agriculture, soil moisture is used for evapotranspiration, droughts, irrigation scheduling, and crop yield forecasting, also for geochemical cycles of carbon, nitrogen, oxygen, phosphorus, calcium and water cycles [2]. It is important for the environmental studies like subsequent precipitation patterns, temperature change and water quality [3]. Remote sensing provide the instantaneous measurement of soil moisture content and its spatial and temporal perspective, to retrieve the soil moisture from satellite data visible, near infrared, thermal infrared and radio channels. From optical and thermal Infrared bands of sun radiations, MODIS satellite data products can be utilized for soil moisture measurement [4-6].

Microwave measurements have the advantage of being largely unaffected by cloud cover but the spatial resolution in passive sensors is courser than the optical sensors. MODIS data in thermal bands (31 and 32) has spatial resolution of 1 Km that are used to calculate land surface temperature, which is mapped through the earth emitted radiations.

Soil moisture, at large scale, from satellite sensors like Advanced Microwave Scanning Radiometer (AMSR-E) and Moderate Resolution Imaging Spector Radiometer (MODIS) for the years 2007 and 2010 was mapped in this study. The year 2007 was a normal year while 2010 was wet with havoc rainfall and flooding. The results of MODIS derived soil moisture is in moderate agreement with AMSR-E soil moisture product proving the effectiveness of high resolution products in optical range.

II. METHODOLOGY

The Land surface Temperature (LST) and Enhanced Vegetation Index (EVI) were applied to construct EVI-LST space to calculate a SMI values. The values of the linear functions LSTmax and LSTmin are calculated from the EVI-LST scatterplot that are used for the calculation of SMI. The intercepts of the Dry edge and wet edge are LSTmax and LSTmin respectively.

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ISSN: 1814-8085 / E-ISSN: 1927-5129/15

$$SMI = \frac{LST + LST_{min}}{LST_{max} - LST_{min}} \quad (I)$$

$$LST_{max} = b_{max} \times EVI + a_{max} \quad (IIa)$$

$$LST_{min} = b_{min} \times EVI + a_{min} \quad (IIb)$$

Where,

LST_{max} is maximum surface temperature derived from the fitting equation of dry edge corresponding to EVI, whose theoretical soil water content should be “0”.

LST_{min} is the minimum surface temperature derived from the fitting equation corresponding to a given EVI, whose theoretical water should be saturated soil.

a_{max}, b_{max} are the linear regression parameters of dry edge

a_{min},,b_{min} are the linear regression parameters of wet edge

A. Study Area

The Sindh province of Pakistan is famous for the Indus River and its ancient civilization like Egypt and Babylon. The eastern side of Sindh is Thar Desert and Kirthar Mountain to the west and the Arabian Sea in the south, the central Sindh is fertile plain around the Indus River. The province lies between 23°40' and 28°29' North latitudes and 66°40' and 71°05' East longitudes. Total area of the province is 140,914 km^2 [7].

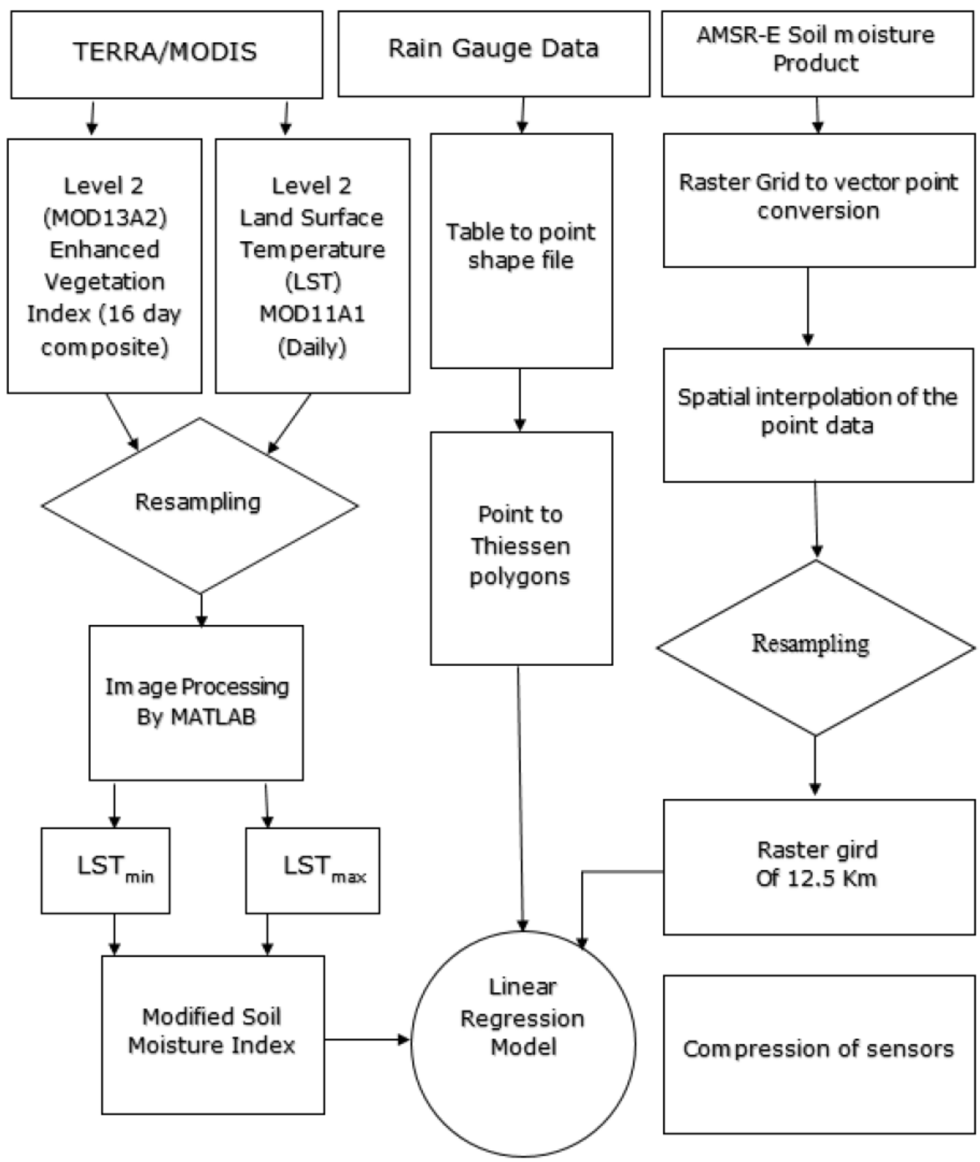

Figure 1: Methodology flow diagram.

It is subtropical region having hot summer and cold in winter. Average temperature maximum from Dec to Jan is 46 °C to 2 °C respectively. Southwesterly monsoon winds brings precipitations with the annual rainfall averages 23 mm. The Figure **1** shows status of land cover and land use areas of the Sindh.

B. Data Acquisition and Data Pre-Processing

1. Remote Sensing Data

Optical, thermal infrared and passive microwave regions of the electromagnetic spectrum were exploited in this study i.e., NIR, Red and blue bands for the Enhanced Vegetation Index (EVI) in optical domain, thermal Infrared band for Land Surface Temperature (LST) and passive microwave region for soil moisture (a level 3 product of AMSR-E) in conjunction with rain gauge 24 hours data. MODIS and AMSR-E sensors with 23 images of MOD13A2 for each year, 75 images of MOD11A1 for the year 2007, 87 for the year 2010 were used in this study.

These remotely-sensed data serve as independent variables in a regression model to estimate soil moisture conditions for the study area.

2. MODIS Satellite Data

The Moderate Resolution Imaging Spector Radiometer (MODIS) onboard the Terra and Aqua satellite platform were launched by NASA in December 1999 and in June 2002 respectively with 12 hours revisit time. It has moderate spatial resolution (nominally 1 kilometer) with high radiometric sensitivity (12 bit) in 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm. Swath width of 2330 km (cross track) with 36 bands with spatial resolution of 250 m (bands 1-2) at nadir, 500 m (bands 3-7), 1000 m (bands 8-36) have sufficient spectral bands in the Visible (VIS) through the Long Wave Infrared (LWIR) region to enable the measurement of numerous (40-50) geophysical parameters. It has ±55-degree scanning pattern at the EOS orbit of 705 km height [8].

3. AMSR-E Satellite Data

Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) sensor on NASA's Aqua satellite (AMSR-E) provides measurements of soil moisture, snow water equivalent, surface wetness, wind speed, atmospheric cloud water, and oceanic water vapor, including precipitation rate, sea surface temperature, sea ice concentration, and atmospheric parameters for the investigation of global water and energy cycles.

It is a twelve-channel passive-microwave radiometer system, six-frequency, polarized vertically and horizontally both at all channels. It measures brightness temperatures at 6.925, 10.65, 18.7, 23.8,

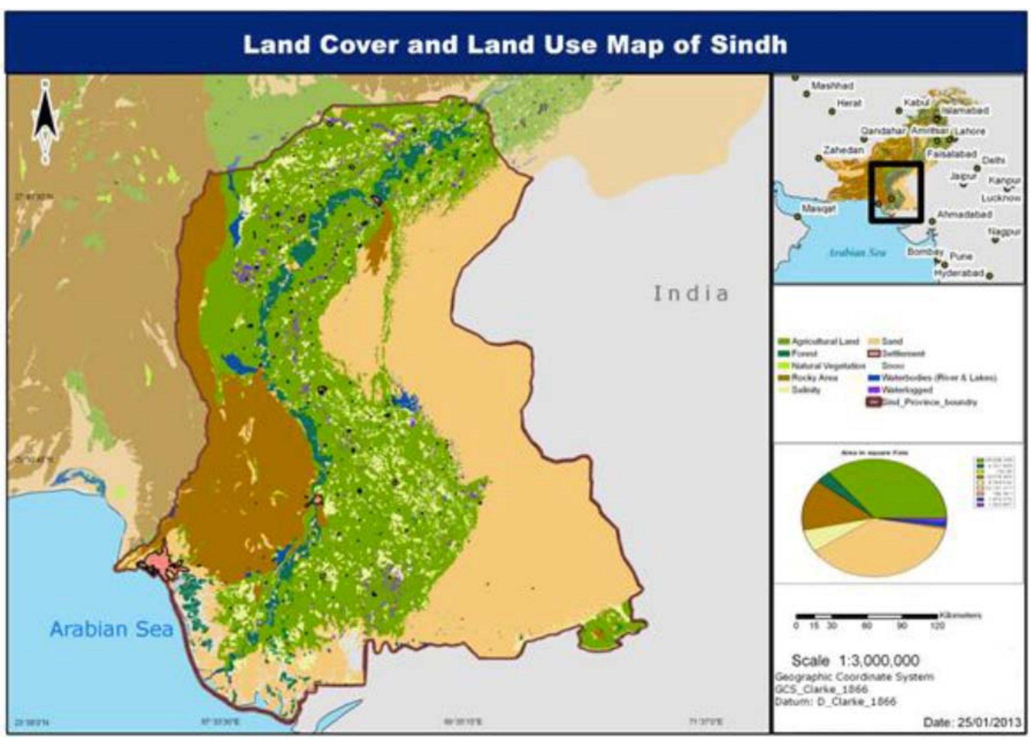

Figure 2: Land Cover and Land Use Map of Sindh Province.

36.5, and 89.0 GHz. The Data products from the daily, weekly, and monthly Level-1A, Level-2A, Level-2B, and Level-3 are available at (http://aqua.nasa.gov/about/instrument_amsr.php), the Data is stored in HDF-EOS format.

Land surface product (AMSR_E_L3_DailyLand), Level-3 gridded data includes daily measurements of surface soil moisture and vegetation/roughness as brightness temperatures and water content. The Ancillary data include time, geolocation, and quality assessment 56 km mean spatial resolution, were resampled to a global cylindrical 25 km Equal-Area Scalable Earth Grid (EASE-Grid) cell spacing.

4. Rain Guage Data

The rain gauge data recorded by Pakistan meteorological department on the WMO standards of measurement every 6 to 24 hours. Thiessen Polygon Method was used for the spatial distribution model.

C. MODIS Enhanced Vegetation Index (EVI MODIS)

The EVI is a highly optimized index, aimed to augment the signals from vegetation. The index utilizes the lessening of atmosphere influences and de-coupling of background signals for enhanced and improved sensitivity in regions of high biomass and for effective monitoring of vegetation (Figure **3A, 3B, 3C, 3D**).

The simple to calculate formula for EVI is expressed as:

$$EVI = \frac{\rho_2 - \rho_1}{\rho_2 + C_2 \times \rho_1 - C_2 \times \rho_3 + L\rho_1} \quad \text{(III)}$$

D. Land Surface Temperature (MODIS)

The MODIS Land Surface Temperature (LST) products MOD11 was used for clear-sky cases, with an accuracy of 1°K. The thermal infrared bands have an IFOV of approximately 1km at nadir. LST is a good indicator of the energy balance at the Earth's surface and the atmosphere. Classification-based emissivity method was used to estimate emissivity of bands 31 and 32 on day and night basis [9]. MOD13A1 is a level 3 daily product of land surface temperature which is georeferenced was used for the study.

For the comparison of Land surface temperature in the study area two images of winter and summer for the years 2007 and 2010 are displayed in the maps (Figures **4**, **5**). The difference of the temperature was kept 5 K in the legend to show the change in temperature. The water bodies had low temperature, sand and sand dunes showed high temperature in both winter and summer seasons at the time of passage of satellite. The vegetative and agricultural land due to evapotranspiration show lower temperature than surrounding areas.

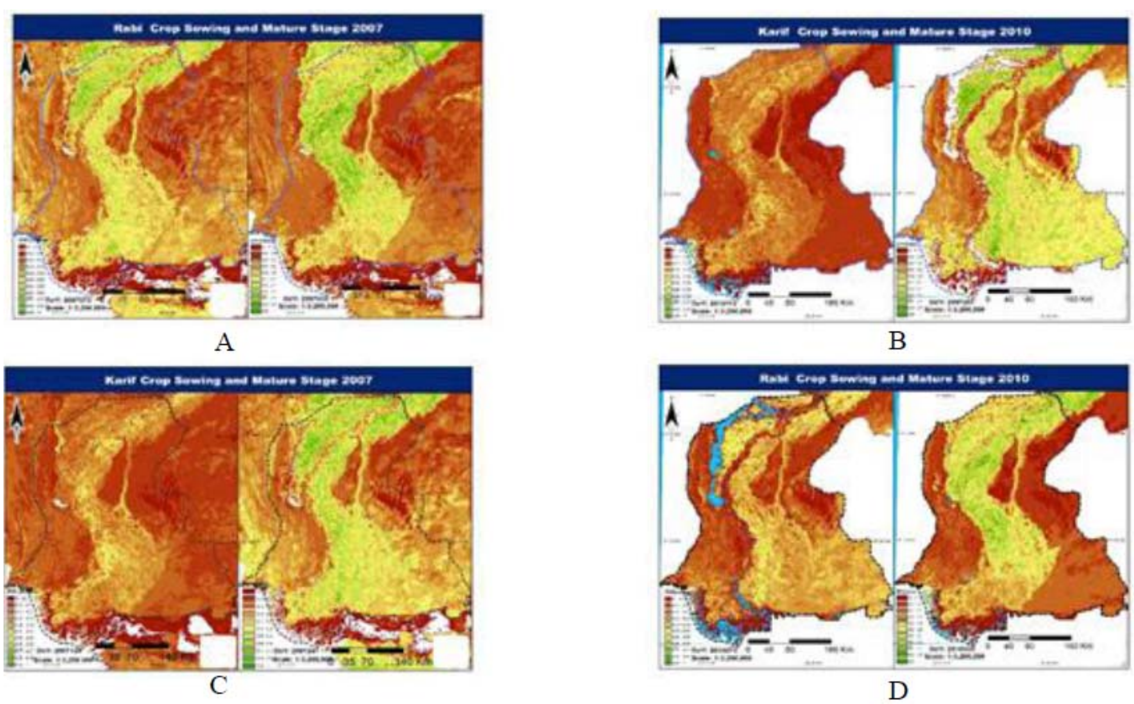

Figure 3: (**A**) Sowing and Mature stage for Rabi Crop in 2007 (**B**) Sowing and Mature stage for Kharif Crop in 2007 (**C**) Sowing and Mature stage for Kharif Crop in 2010 (**D**) Sowing and Mature stage for Rabi Crop in 2010.

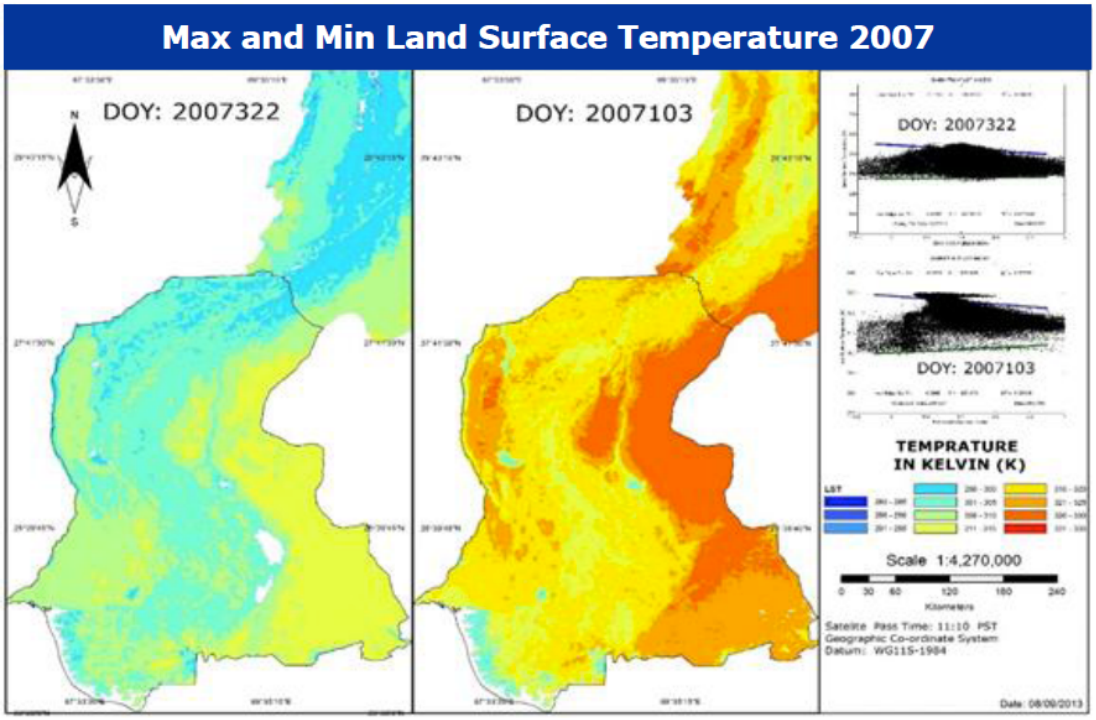

Figure 4: Comparison of LST for Hottest and coldest days in year 2007.

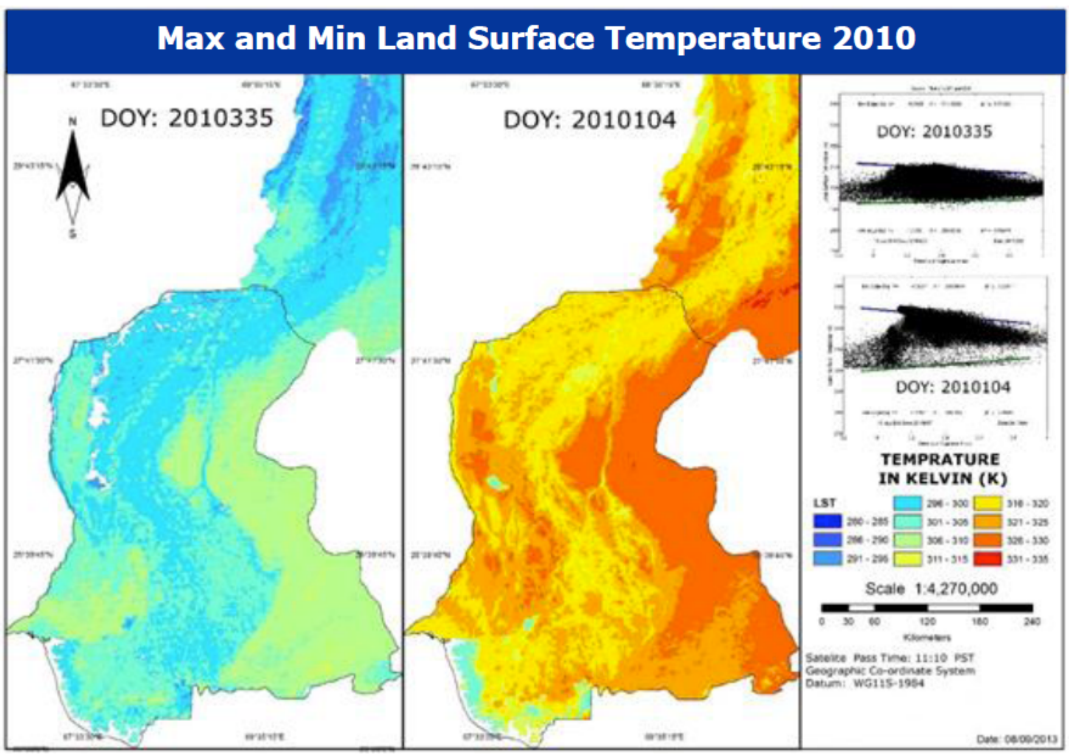

Figure 5: Comparison of LST for Hottest and coldest days in year 2010.

E. Triangle Method

The integration of surface temperature and vegetation indices was performed by SMI for monitoring of soil moisture with a broader assortment of applicability.

The remotely sensed LST and NDVI construct the triangle scatter diagram in the area with vegetation coverage. Theoretically, the scatter plot formed by vegetation index and Land Surface Temperature (LST) should be like a triangle (Figures **6**, **7**). The condition

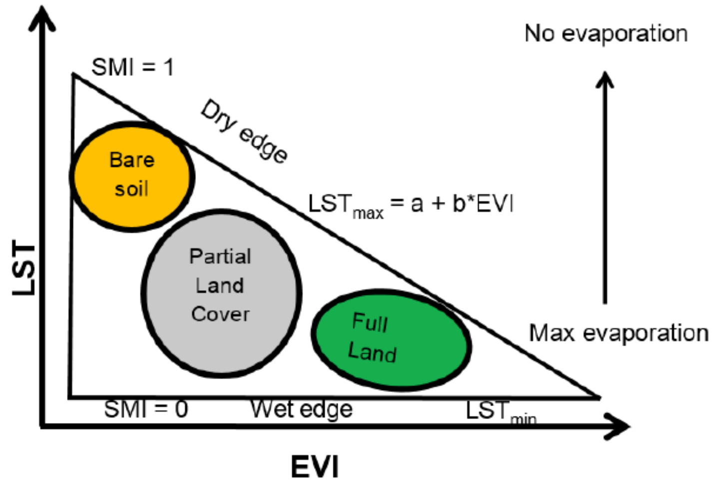

Figure 6: Triangle Method for Soil Moisture Retrieval.

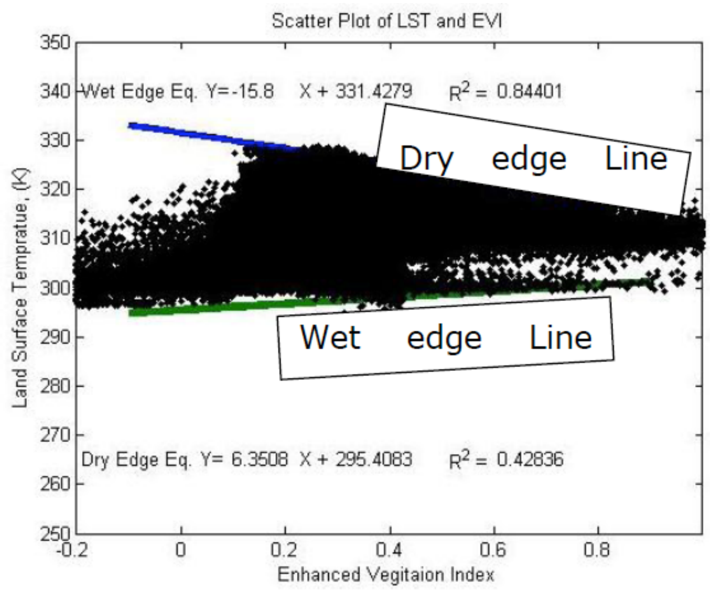

Figure 7: MATLAB Derived Scatter Plot of Triangle Method.

from bare soil is where the value of vegetation index is less and value of LST is low. The brown circle shows the particular area of bare soil. When the value of vegetation index is high and LST is less then it shows the condition of complete coverage [10]. The upper edge of the triangle is defined as dry edge while the lower one is wet edge. Pixels close to the dry edge are comparatively drier while those close to the wet edge are wetter. The position of pixel in the scatter plot defines its moisture condition.

1. Soil Moisture Index (SMI)

The flow diagram for methodology of the case study is described in Figure **1**. AMSRE soil moisture data product was in the form of raster gird of 25 Km in the units of gm/cm^3 the spatial resolution was quite courser compared to MODIS data (1km) but had good accuracy. To transform data in same spatial resolution AMSR-E soil moisture data was spatially interpolated to 12.5 Km^2.

AMSR-E soil moisture was converted to vector points to interpolate the in-between values. Kriging tool was used to interpolate these values then resampled the image in 12.5 Km spatial resolution.

A MATLAB code was developed for the scatter diagram and calculation of the dry edge and wet edge equations along with the SMI, prepared presentation of the output data in the form of the defined colors in 10 classes of soil moisture (Figure **8**). There were 11 rain gauge stations available in the study area. Taking these stations as the ground points Theissen polygon

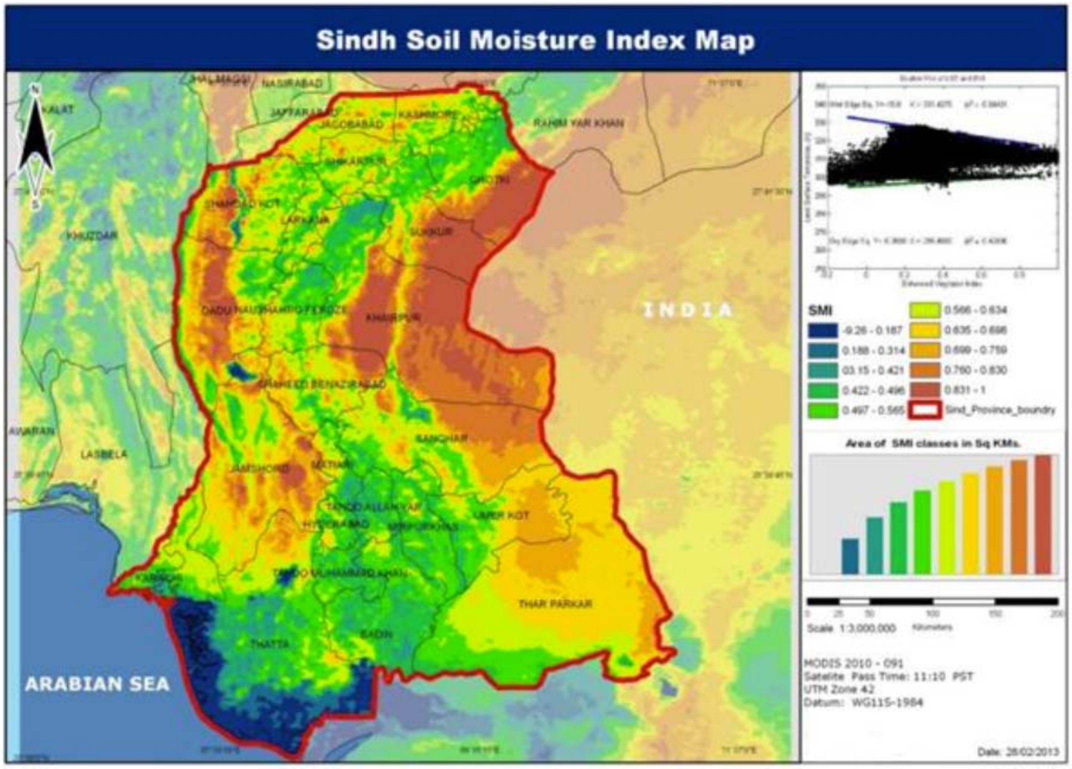

Figure 8: SMI classes' representation.

was used model for the spatial distribution of the data in the study area.

For analysis purpose, the pixel values were extracted in the geolocation of stations in the image. The value of one 12.5 Km pixel was averaged with its surrounding 8 pixels that make 3x3 kernel window of 9 pixels. These values were extracted from both MODIS derived Soil Moisture Index and AMSR-E soil moisture spatially interpolated data.

III. RESULTS AND DISCUSSION

Ten classes were prepared to present the Soil Moisture Index (SMI) these classes are represented in the map Figure **8**. The soil moisture retrieved from the MODIS satellite data was realistic to the land cover area. The moist surface area is represented by blue and green color and the dry area is represented by brown color as the value of the Soil Moisture Index increases the dryness also increases. The equations of dry and the wet edges are;

$Y = -15.8\, x + 331.42$ The equation of the dry edge

$Y = 6.35\, x + 295.3$ The equation of wet edge

The gradient and intercept of equation of dry and wet edges depicts distribution of pixels with the evaporation and saturation areas, the maximum and the minimum temperature boundary limits in which the study area lies.

A. Changes in Wet and Dry Areas

To compare change in area for the wet and dry region in Sindh province, the ten classes were merged into the five different classes' namely moist, moderate moist, normal, moderate dry and dry. The number of pixels for each class represents the spatial area covered by each class. The total area of the study area remain theoretically same but practically cloud masked areas are included in total area so total area in each image does not remain constant around the year. To compare change in the area of dry and moist classes, masked areas are excluded from the total area.

Total area vary in all image of Sindh province therefore the change in area is measured in a ratio of area of each class divided by the total area of the Sindh province excluding few cloudy areas. The change in areas during the years 2007 and 2010 in percentages are presented (Figure **9**, **10**). The graph for the soil moisture index classes shows in summer season (Pre Monsoon) the temperatures remained high so the soil became dry therefore dry areas were increased and wet areas were reduced but in the

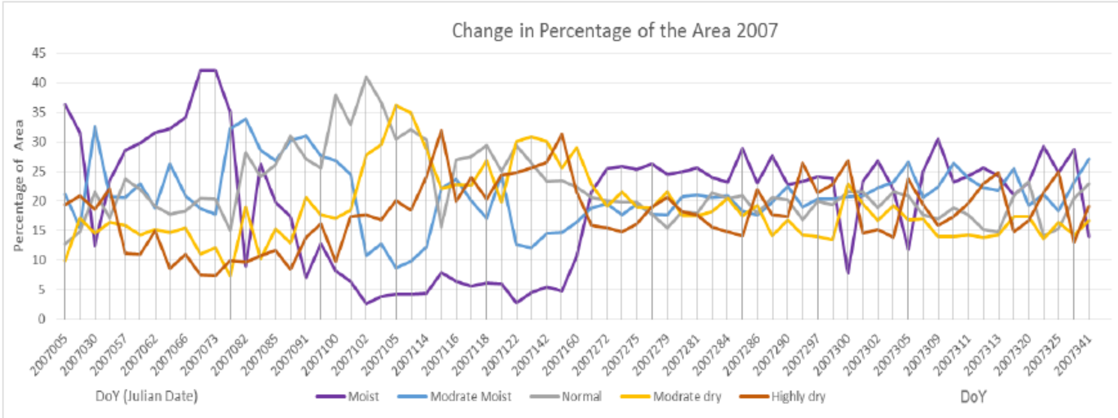

Figure 9: Change in Percentages of areas of each class for the year 2007.

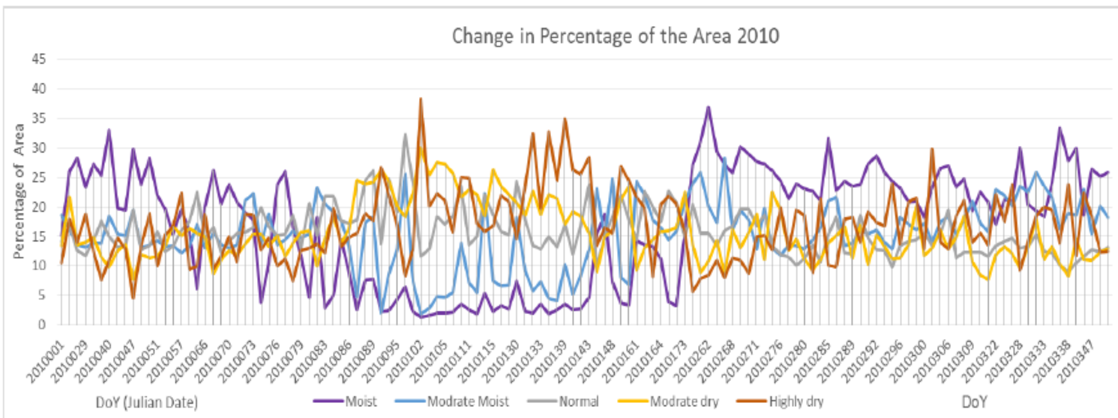

Figure 10: Percentages of areas of each class for year 2010.

monsoon season the dry areas were reduced as the wet areas increased. As 2007 was dryer year than 2010 therefore moist area drastically increased during Monsoon and remain dominant in 2010. Similarly the change in area in the winter rainfall during January, 2010 and February, 2007 were also evident.

B. Comparison Analysis

The linear regression analysis was used to convert MODIS SMI data to soil moisture for each station according to the linear regression model equations of each station. The results of the regression analysis and their standard errors are presented by the graphs (Figures **11**, **12**, **13**, **14**, **15**).

The rain data is also incorporated to show the agreement of the data with the ground data. The values of AMSR-E soil moisture are found to be in agreement with the rain data.

The linear regression analysis of 12.5 Km pixel size with 3x3 kernel window is also presented in Figure **16**.

IV. CONCLUSION AND RECOMMENDATION

The MODIS and AMSRE soil moisture data has their own advantages and few limitations. MODIS give good spatial resolution in clear skies, In case of the passive sensors spatial resolution is poor but data available even in the clouds. The results shows that these satellites are significantly correlated to each other in soil moisture measurements. The agricultural stations having loamy and clayey soil (Sukkar, Larkana, Moin-jo-Daro and Hyderabad) have value of correlation coefficient more significant negative correlation with the MODIS Soil moisture index data and AMSR-E soil moisture data (less than -0.5).

The interpolation technique for comparison is not suitable but pixel to pixel comparison is more suitable method. The correlation results for the year 2010 are better in agreement as compared to year 2007.

It is recommended that in situ data is very important for the remote sensing purpose so a large field campaign should be launched to get better and reliable

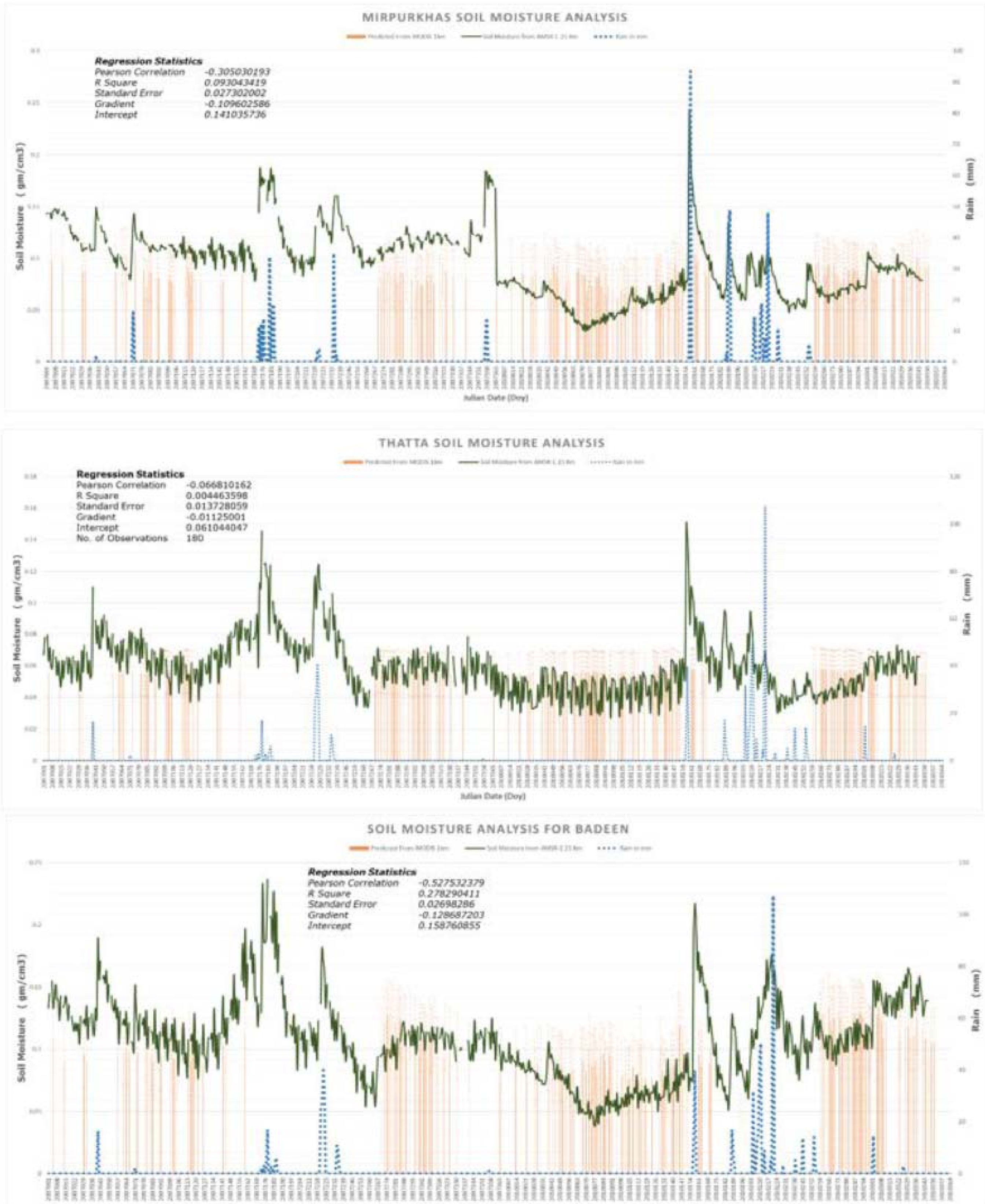

Figure 11: Soil Moisture Analysis for Mirpurkhas, Thatta and Badin.

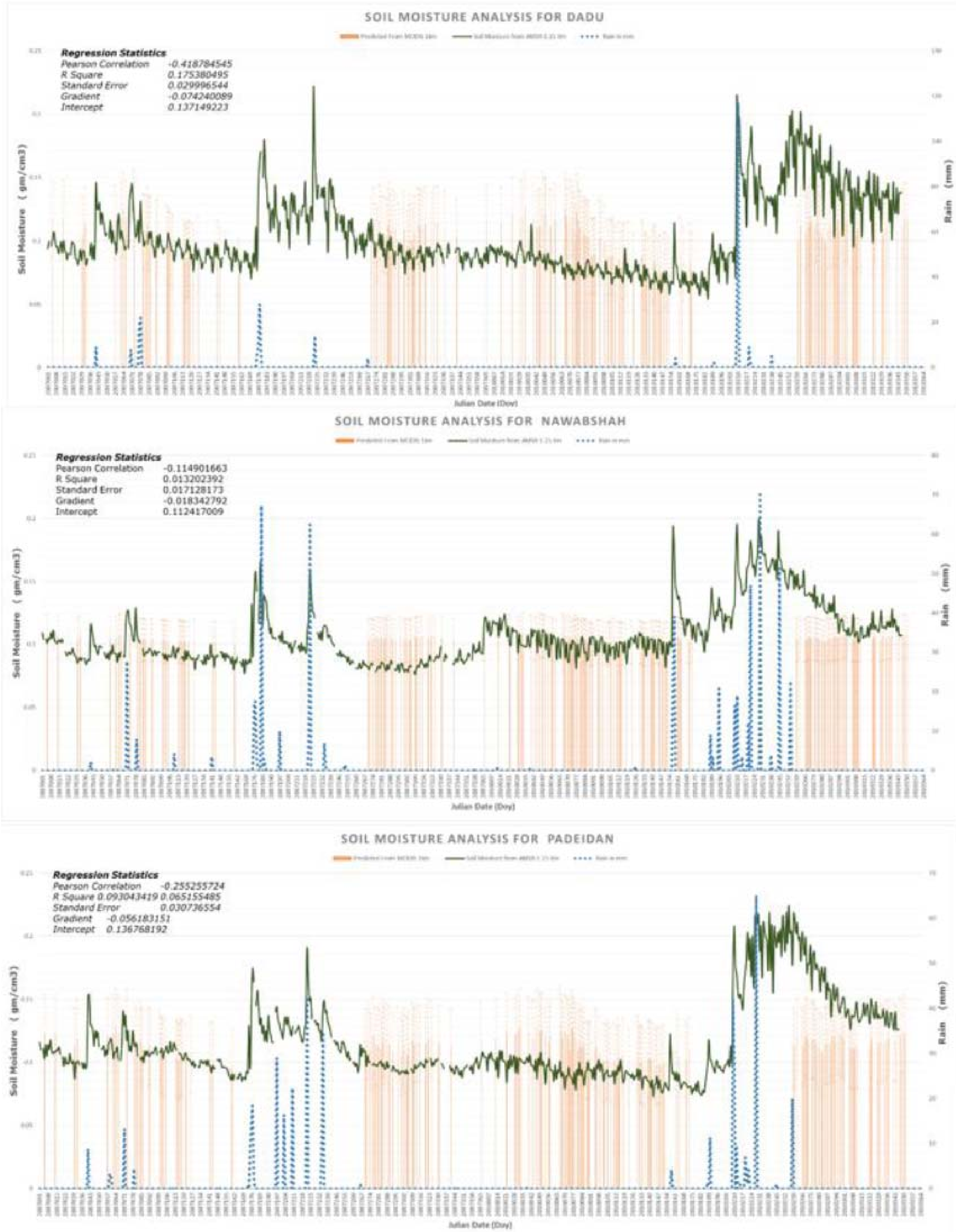

Figure 12: Soil Moisture Analysis for Dadu, Nawabshah and Padeidan.

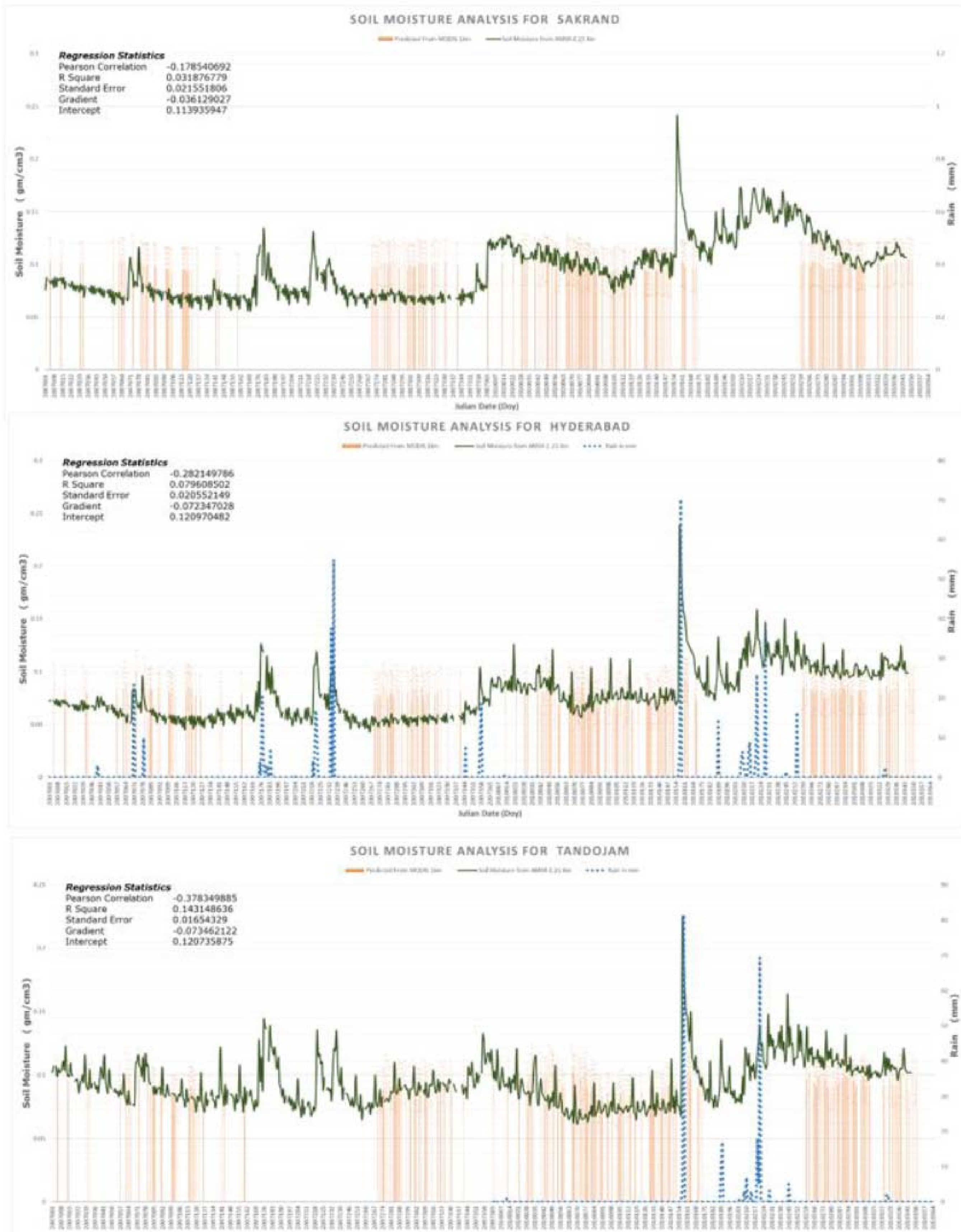

Figure 13: Soil Moisture Analysis for Sakrand, Hyderabad and Tandojam.

Figure 14: Soil Moisture Analysisfor Sukkur and Kirthar Range.

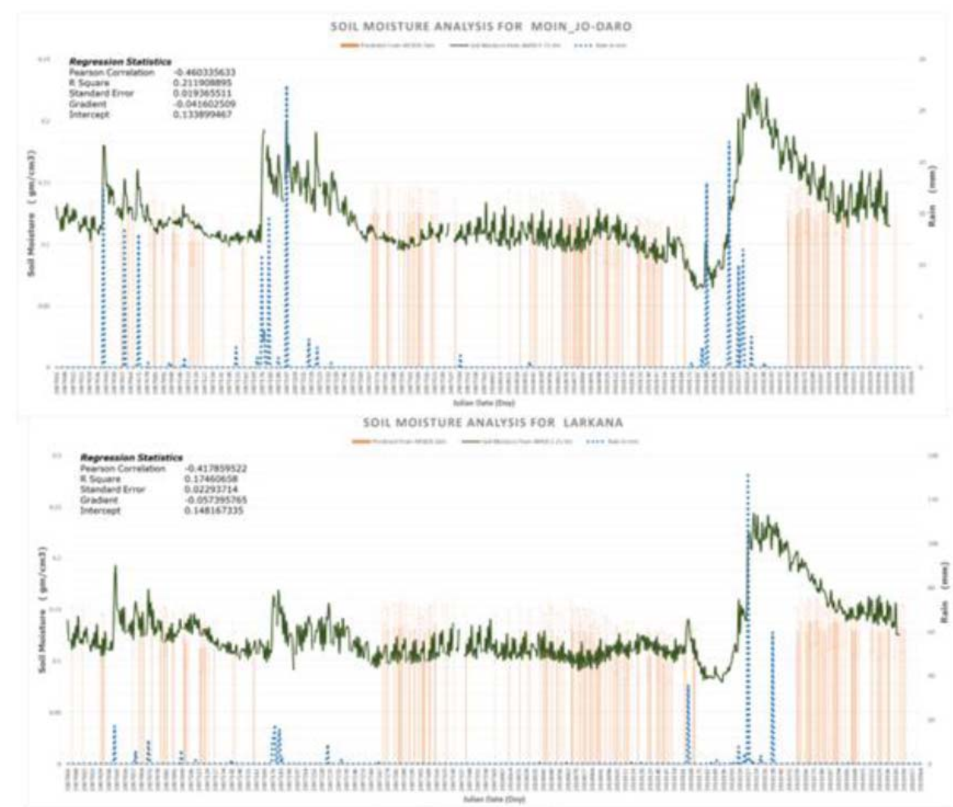

Figure 15: Soil Moisture Analysis for MoinjoDaro and Larkana.

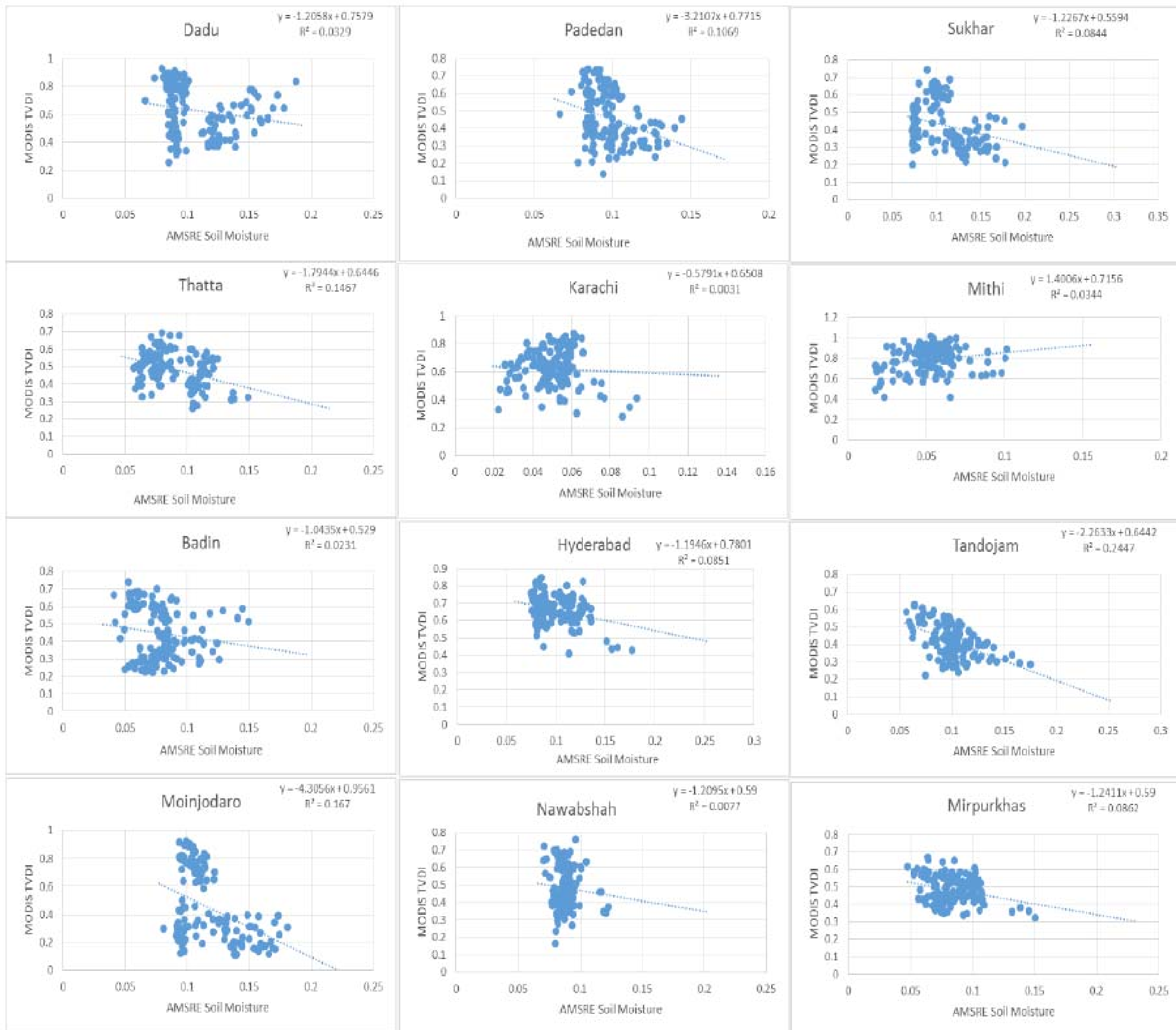

Figure 16: Regression Analysis of 12.5 Km Pixel Size with 3x3 Kernel Window.

results. For comparison of the sensor's results a high resolution soil type mapping could be used to model the soil moisture and water management plans.

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Received on 20-01-2015 Accepted on 16-02-2015 Published on 05-03-2015

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