Solar Resource Mapping in Pakistan

SITE EVALUATION REPORT

July 2015
This report was prepared by the consultants listed on the following pages, under contract to The World Bank.

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This document is an interim output from the above-mentioned project. Users are strongly advised to exercise caution when utilizing the information and data contained, as this has not been subject to full peer review. The final, validated, peer reviewed output from this project will be the Pakistan Solar Atlas, which will be published once the project is completed.

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1 Executive Summary

A team of the solar vendor consortium for the ESMAP Pakistan Solar Resource Mapping Project visited the Pakistan Meteorological Department (PMD) office in Quetta on August 28, 2014. The goal was to evaluate if the location is suitable for the installation of a solar ground measurement station in the framework of the project.

Two different sites have been examined on the campus, one on the roof of an office building on the PMD location and one on the ground at the meteorological measurement station of PMD.

Site 2, the ground site at the meteorological station, is recommended for the installation of a Tier2 meteorological station (CSP Services MDI automatic weather station).

2 Procedure and tasks of the site visit

The following tasks have been performed for the site visit, following the procedure from the site visit manual:

1. Recording of exact geographic coordinates of the site(s) and orientations
2. Photographic documentation of the site
   - Overview of site and location,
   - panoramic 360 degrees round view from the site for identification of potential obstacles blocking the sun path
3. Check of availability, strength and potential providers of GSM network at the site
4. Audit of local staff to clarify all relevant information (see checklist)
5. Information of local staff at the site about the project, its aim and required tasks for realization and clarification of availability and prospected quality of the required support from their side
6. In-office evaluation of results and compilation of this report
3 Site visit results
The results of the site visit and its evaluation is presented in the following section.

3.1 Overview, description of the site and surroundings

Figure 1: Location overview (Google Maps View)

Figure 2: Aerial View (Google Earth View)
The PMD office in Quetta is located in the north of the city to the east of the International Airport. South of the site, the city of Quetta is located with dense population and settlement. To the east, sub-urban settlements extend for about 4 km after there is open terrain with a military airfield, followed by the slopes of the surrounding mountains.

Quetta, the capital of Balochistan province, is located about 80 km east of the Pakistan-Afghanistan frontier. The city is surrounded by hills and mountains of the Sulaiman mountain ranges, namely the Chiltan, Takatoo, Murdar and Zhargur ranges. About 90 km to the west, behind the Chiltan range, the Regestan Desert in Afghanistan commences.

3.2 Local support, maintenance staff and future hardware use

The availability of qualified staff for the regular local maintenance (cleaning of sensors and other parts, visual inspection, surveillance of equipment) and the institutional support of the involved stakeholder are directly relevant for the success of the ESMAP project measurement campaign.

Future use of the equipment after the ESMAP project termination is another issue to be considered in order to provide maximum sustainability of the project.

Local support and maintenance staff

Local staff is available and confirmed to be willing to perform maintenance tasks throughout the 24 months of the measurement campaign. A short briefing about the required tasks and their frequency of occurrence has been given to PMD representatives. Qualification of local staff for the task is assumed to be given, since PMD is the official department of meteorology with corresponding staff and there is already meteorological equipment present and operating under their control. The data from this instrumentation could potentially be an extra input for cross-check of the ground measurement data within the ESMAP campaign.

Future hardware use (sustainability)

The meteorological station from the ESMAP project would be a good complementary station to the existing PMD meteorological station. The station would likely be used actively in future for the national measurement network of PMD and the value added therefore be increased.

Contact Information

The local contact for the site is

- Arif Khan
  PMD Office, Shaikh Manda, Airport Road, Quetta, Balochistan
  +92 300 3830630
3.3 Site 1 (roof top)

3.3.1 Coordinates

N 30.2424° E 66.9869°, altitude 1640 m above mean sea level

Site 1 is located on the roof of the office building of the PMD office complex.

![Figure 3: View from Site 1 to the North](image)

![Figure 4: View from Site 1 to the South](image)

3.3.2 Checklist for evaluation of the situation of and at the site

The following checklist has been filled at the site visit and is completed by interviewing stakeholders on site.

Table 1: Site checklist for site 1

<table>
<thead>
<tr>
<th>Criteria/Measure</th>
<th>Yes / No</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions(^i)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum area 10 × 10 m(^2)</td>
<td>Yes</td>
<td>Rooftop</td>
</tr>
<tr>
<td>Surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm natural ground(^ii)</td>
<td>-</td>
<td>No</td>
</tr>
<tr>
<td>Ground type(^iii)</td>
<td>-</td>
<td>Concrete</td>
</tr>
<tr>
<td>Horizontally levelled(^iv)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Excavation for foundations possible(^v)</td>
<td>-</td>
<td>Casting Blocks are preferred</td>
</tr>
<tr>
<td>Fencing of the site possible(^vi)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>No drifting sand/snow(^vii)</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>No flooding possible(^viii)</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Surroundings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obstructions</td>
<td>Yes</td>
<td>Trees. See Panoramic</td>
</tr>
</tbody>
</table>

\(^i\) Dimensions: Minimum area 10 × 10 m\(^2\) required.

\(^ii\) Firm natural ground: Not acceptable.

\(^iii\) Ground type: Concrete preferred.

\(^iv\) Horizontally levelled: Yes.

\(^v\) Excavation for foundations possible: Casting Blocks are preferred.

\(^vi\) Fencing of the site possible: Yes.

\(^vii\) No drifting sand/snow: No.

\(^viii\) No flooding possible: No.
<table>
<thead>
<tr>
<th><strong>If yes, note direction, distance and approx. height</strong>&lt;sup&gt;ix&lt;/sup&gt;</th>
<th><strong>Pictures. (Trees can be cut down if required)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reflections or light sources</strong>&lt;sup&gt;x&lt;/sup&gt;</td>
<td>-</td>
</tr>
<tr>
<td><strong>Industrial areas or power plants</strong>&lt;sup&gt;xi&lt;/sup&gt;</td>
<td>No</td>
</tr>
<tr>
<td><strong>Sources of smoke or vapor</strong>&lt;sup&gt;xii&lt;/sup&gt;</td>
<td>No</td>
</tr>
<tr>
<td><strong>Quarry or mine</strong>&lt;sup&gt;xiii&lt;/sup&gt;</td>
<td>No</td>
</tr>
<tr>
<td><strong>Main road, dirt road, track</strong>&lt;sup&gt;xiv&lt;/sup&gt;</td>
<td>Paved Roads</td>
</tr>
<tr>
<td><strong>Airports</strong>&lt;sup&gt;xv&lt;/sup&gt;</td>
<td>- 4km away</td>
</tr>
<tr>
<td><strong>Settlements, towns, city</strong>&lt;sup&gt;xvi&lt;/sup&gt;</td>
<td>Yes Urban Area</td>
</tr>
<tr>
<td><strong>Agricultural area</strong>&lt;sup&gt;xvii&lt;/sup&gt;</td>
<td>No Quite Far</td>
</tr>
<tr>
<td><strong>Swamp, lake, river, ocean</strong>&lt;sup&gt;xviii&lt;/sup&gt;</td>
<td>No</td>
</tr>
<tr>
<td><strong>Sand dunes</strong>&lt;sup&gt;xix&lt;/sup&gt;</td>
<td>No</td>
</tr>
<tr>
<td><strong>Animal populations</strong>&lt;sup&gt;xx&lt;/sup&gt;</td>
<td>No</td>
</tr>
<tr>
<td><strong>Occurrence of snowfall</strong>&lt;sup&gt;xxi&lt;/sup&gt;</td>
<td>Yes In winters</td>
</tr>
<tr>
<td><strong>Temperatures below freezing point</strong>&lt;sup&gt;xxii&lt;/sup&gt;</td>
<td>Yes Temperature can reach upto -10°C</td>
</tr>
<tr>
<td><strong>Other</strong>&lt;sup&gt;xxiii&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Accessibility</strong></th>
<th><strong>Accessible by car</strong>&lt;sup&gt;xxiv&lt;/sup&gt;</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GSM coverage</strong></td>
<td><strong>2G network available</strong>&lt;sup&gt;xxv&lt;/sup&gt;</td>
<td>Yes All five</td>
</tr>
<tr>
<td><strong>Grid power</strong></td>
<td><strong>Electricity available</strong>&lt;sup&gt;xxvi&lt;/sup&gt;</td>
<td>Yes 6 hours power outage per day.</td>
</tr>
<tr>
<td><strong>Land use rights</strong></td>
<td><strong>Permit available</strong>&lt;sup&gt;xxvii&lt;/sup&gt;</td>
<td>Yes Approval to be given by PMD</td>
</tr>
<tr>
<td><strong>Operation permit</strong></td>
<td><strong>Permit available</strong>&lt;sup&gt;xxviii&lt;/sup&gt;</td>
<td>Yes Approval to be given by PMD</td>
</tr>
<tr>
<td><strong>Security</strong></td>
<td><strong>No underground or overhead electrical lines, pipelines or similar</strong>&lt;sup&gt;xxix&lt;/sup&gt;</td>
<td>No Feeder and Transformer in the east</td>
</tr>
<tr>
<td></td>
<td><strong>Measures against theft or vandalism required?</strong>&lt;sup&gt;xxx&lt;/sup&gt;</td>
<td>No</td>
</tr>
</tbody>
</table>
Regarding the aspects covered by the checklist, site 1 is well suited for the installation of a ground measurement station. The installation on a roof-top is a good option since it elevates the station above many obstacles; the stakeholder representatives recommend placing a guard to avoid vandalism from inhabitants of nearby settlements. The direct surroundings lack any industrial facility thus no negative impacts on irradiation and measurement conditions is stated. All roads in the surroundings are paved and therefore not heavily dust-emitting; large water bodies are at least several kilometres distant. A certain setback is of course the location within a large town, which emits a certain amount of pollutants and might differ somewhat from the meteorological characteristics in the surroundings. No special permits are required and permission to use the site can be given by the PMD.

3.3.3 Shadings and Reflections

Panoramic View
The picture in Figure 5 shows a panoramic view with a centered south view, North is on the left and right edge of the picture. Blue markers show the North, South, East and West direction as well as horizon height. The sun paths throughout the year are displayed in the picture, revealing if any objects on the horizon are imposing an obstruction to the direct solar irradiance.

![Figure 5: Panoramic View with North, South, horizon line and monthly sun paths with the corresponding position at full hours marked](image)

From the panoramic view, it is visible that a few obstacles such as trees, on the horizon are blocking the sun especially at sunset. The impact is further analyzed in the following paragraphs.
Figure 6: Shading Table for Sun Elevations >0°

Figure 6 shows the shading table throughout the year. It becomes clear that throughout the year, many shadings are obstructing the sensor in the evenings (up to about 2 hours) and also in the morning (up to about 45 minutes).
Shading Table for Sun Elevations >5°

Figure 7: Shading Table for Sun Elevations >5°

Figure 7 shows the shading table after excluding Sun Elevations smaller than 5° above horizon. At these low angles, measurement uncertainty of satellite and ground measurement is elevated due to the large cosine error, and the data from these periods is therefore excluded from the satellite data adjustment and validation. Also from the view of any solar power installation (PV or CSP), sun elevation smaller than 5° is usually not contributing to electricity or heat generation due to shading, unfavorable incidence angles and low irradiance intensity. *Subsequently, all further graphs and evaluations refer to sun elevations larger than 5°, as the main aim of the measurements on ground is the adjustment of the long-term satellite data.*

From the graph, it is visible that shading still occurs in the evenings throughout the summer months in the evening hours and also in the morning in May, August and November to February.
Direct Shading Impact

Figure 8 shows the impact of shading on direct normal irradiation (DNI). DNI is modeled according to Bird (Bird et al., 1991) as a theoretical clear-sky DNI throughout the year and can be interpreted as the maximum solar resource. The impact of shading on this figure is therefore the maximum quantitative impact shading could have on solar resource.

Figure 8: Shading Impact on BirdDNI for Sun Elevations >5°

From the figure, it is clearly visible that shadings have a certain impact throughout the months from March to October.

Figure 9: Shading Impact for Sun Elevations >5°

Figure 9 shows the impact of direct shading due to the reported obstructions. The left figure shows the percentage of time for all calendar months which is affected by
direct shading. In total, about 4.1 % of the time is affected by direct shading, with up to 9% in the months of May and August. The right figure shows the quantitative impact of shading on the Bird-DNI summarized for each month. For the whole year, the reduction of the annual Bird-DNI sum due to direct shading is about 6.1 %.

**Diffuse Shading and Reflections**

Diffuse shading and reflections of any mentionable quantity are not to be expected since no large obstacles close to the site and no highly reflective surface above sensor height can be identified.

### 3.4 Site 2 (ground station)

**3.4.1 Coordinates**

N 30.2428°  E 66.9865°, altitude 1630 m above mean sea level

Site 2 is located on the ground at the place where the existing meteorological station of PMD is installed.

![Figure 10: View from Site 2 to the North](image1.png)  ![Figure 11: View from Site 2 to the South](image2.png)
3.4.2 Checklist for evaluation of the situation of and at the site

The checklist is only displayed for the lines which differ from the checklist for site 1.

<table>
<thead>
<tr>
<th>Criteria/Measure</th>
<th>Yes / No</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions³xxii</td>
<td>Minimum area 10 × 10 m²</td>
<td>Yes</td>
</tr>
<tr>
<td>Surface</td>
<td>Firm natural ground³xxiii</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Ground type³xiv</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Horizontally levelled³xv</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Excavation for foundations possible³xvi</td>
<td>-</td>
</tr>
<tr>
<td>Surroundings</td>
<td>Obstructions</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>If yes, note direction, distance and approx. height³xxxvii</td>
<td></td>
</tr>
</tbody>
</table>

Regarding the aspects covered by the checklist, site 2 is well suited for the installation of a ground measurement station. The installation on natural ground is recommended by WMO and there is sufficient free area around the station. The direct surroundings lack any industrial facility thus no negative impacts on irradiation and measurement conditions is stated. All roads in the surroundings are paved and therefore not heavily dust-emitting; large water bodies are at least several kilometres distant. A certain setback is of course the location within a large town, which emits a certain amount of pollutants and might differ somewhat from the meteorological characteristics in the surroundings. No special permits are required and permission to use the site can be given by the PMD.

3.4.3 Shadings and Reflections

Panoramic View

Figure 12: Panoramic View with North, South, horizon line and monthly sun paths with the corresponding position at full hours marked

From the panoramic view, it is visible that only few obstacles are blocking the sun.
Figure 13: Shading Table for Sun Elevations >0°

Figure 13 shows the shading table throughout the year. It becomes clear that throughout the year, brief obstructions of up to 20 minutes at sunrise and a few minutes at sunset are present.
Figure 14: Shading Table for Sun Elevations $>5^\circ$

Figure 14 shows the shading table after excluding Sun Elevations smaller than $5^\circ$ above horizon. Subsequently, all further graphs and evaluations refer to sun elevations larger than $5^\circ$, as the main aim of the measurements on ground is the adjustment of the long-term satellite data.

From the graph, it is visible that shading is practically eliminated except a few minutes in the morning in February and October.
Direct Shading Impact

From Figure 15, it is clearly visible that shadings have no mentionable impact.

![Figure 15: Shading Impact on BirdDNI for Sun Elevations >5°](image)

Figure 16 shows the impact of direct shading due to the reported obstructions. The left figure shows the percentage of time for all calendar months which is affected by direct shading. In total, almost 0 % of the time is affected by direct shading with a maximum in February and November of 0.3 %. The right figure shows the quantitative impact of shading on the Bird-DNI summarized for each month. For the whole year, the reduction of the annual Bird-DNI sum due to direct shading is 0.1 %.

Diffuse Shading and Reflections

Effects of diffuse shading and reflections are expected to be non-existent.
4 Conclusion

The surroundings of the location are acceptable for the installation of a ground measurement station. No significant single external influence from surrounding facilities on the overall meteorological and atmospheric conditions could be stated during the site visit, however the location within the city might have some minor influence on the representativeness of the measurements for the surroundings. The local stakeholder confirmed his support and smooth operation and proper maintenance of the station is expected with high probability. Future use of the equipment by the local stakeholder after the two years measurement campaign is also probable, the sustainability of installing a meteorological station at PMD Peshawar is expected to be high.

Site 2 is recommended for the installation of a Tier 2 meteorological station, because the ground station installation is closest to the recommendations of WMO for siting of meteorological stations and because there is an already existing station of PMD on this site. This allows for easier maintenance because the operators do not have to make an extra way, and furthermore allows for cross-checking the measurement data with the data from the existing station for quality control. Also, for the long-term sustainability it is expected that a station according to WMO recommendations is more useful to the PMD.
Detailed description of checklist criteria:

i. A site with a minimum extension of $10 \times 10$ m$^2$ is required for the collocation of the meteorological measurement equipment, complying with the characteristics and criteria listed in the following.

ii. The site suitable for collocation of a meteorological station needs to have a firm ground in order to enable a secure fixation of the equipment on the ground, e.g. by ground anchors and guying ropes.

iii. Annotate here if the ground consists of firm and naturally grown soil or artificially (by man) filled soil, if it consists of bedrock, firm soil, loose soil or sand.

iv. Annotate here if the site is approximately horizontally levelled and flat.

v. Annotate here if it is possible and permitted to lay small foundations (4-5 foundations each approximately $1 \times 1$ m$^2$ and ~0.3 m deep).

vi. Annotate here if it is possible and permitted to fence the compound.

vii. Annotate here the terrain consists of drifting sand or snow.

viii. Annotate here if the terrain may run the risk to be flooded at heavy rain falls.

ix. Describe any object which exceeds 2 m height in the closer environment of the site and which might shade the measurement equipment on the site from direct sun at any time of the year or which obstructs parts of the sky dome. Describe in detail at least all such objects within 30 m distance as well as bigger objects up to at least 200 m distance from the site. As the sun at sun rise and sun set approaches the horizon in East and West direction (~±30 degrees depending on season), obstructions in these directions are of particular importance. Add sketches of the site environments where possible. Possible obstructing objects are: mountains, hills, buildings, skyscrapers, houses, industrial or commercial buildings, warehouses, churches/mosques or similar buildings (for religious or cultural activities), walls, bridges, towers, chimneys, wind energy plants, transmission masts, power poles, other poles or rods, cranes, street lights, greenhouses, trees, bushes, shruberies, any other higher vegetation, or similar. Moreover, the view from the site towards the horizon should be documented by 360º photographs (see corresponding description) or a short movie taken from the site, starting in direction to the North over East, South, and West to North direction again.

x. Annotate if any reflecting surfaces like mirrors, glazing, shiny metal surfaces, PV panels, etc., or artificial light sources are in the environments and might cause reflections or radiation on the measurement equipment, influencing irradiation measurements.

xi. Annotate if any industrial production site or power plant is located in the environments of a few kilometers, which may cause emissions of smoke, vapor, dust or other aerosols.

xii. Annotate any source of smoke or water vapor columns located in the environments.

xiii. Annotate quarries or mines in the environments causing pollution by elevated dust.
xiv Annotate close by roads as they frequently cause increased sensor soiling by elevated dust settling down on the sensors, or increase the risk for theft or vandalism due to increased visibility.

xv Annotate the presence of airports in the environments as exhaust gases of planes may influence the measurements.

xvi Annotate the presence and size of settlements in the environments in order to judge potential influences on the measurements (personally or as secondary effects like smoke or dust) by man.

xvii Annotate type and frequency (if possible) of agricultural activities in the environments in order to judge potential impacts on the measurements (e.g. elevated dust, etc.).

xviii Annotate their potential presence in the environments in order to judge impacts on the measurements due to increased humidity, oxidation of the equipment, instability of the ground, etc.

xix Annotate the presence of sand dunes in the proximities of some kilometers in order to judge potential deposition of sand on the equipment.

xx Annotate if any animal population frequents the area which might have any impact on the measurements. Also take into account birds, termites, insects (bees, wasps, etc.), etc.

xxi Annotate the occurrence and the frequency (if possible, may be estimated) of days with snowfall or remaining snow cover in order to design the power supply and version of the irradiation sensor(s).

xxii Annotate the occurrence and the frequency (if possible, may be estimated) of days with temperatures below freezing point temperature (zero degrees Celsius) in order to design the equipment and judge potential impacts on the measurements.

xxiii Annotate any other observations, occurrences or presences which you may estimate them causing potential impacts on the measurements. In the case of doubt about an influence, please annotate the observation.

xxiv Annotate if the site is easily reachable by car in order to facilitate the transport of the equipment to the site.

xxv Verify with your mobile phone or contacting a reliable local mobile phone network provider the availability of 2G network from different providers. If only 3G network (or higher) is available, verify with the network provider if GPRS connection in 2G mode is enabled. Check with your mobile phone by switching it manually to 2G connection only and test data connectivity via GPRS or EDGE.

xxvi Annotate if electricity grid is available at the site for power supply. If information is available, annotate the voltage level and if grid stability issues are known for the site.

xxvii Verify and annotate if the land use permits are conceded or given from the land owner.

xxviii Verify and annotate if the permits to use the compound for operation of a meteorological station are conceded or given by law and local authorities.

xxix Verify and annotate if no high voltage lines (exceeding 20 V) are crossing the compound neither as overhead line nor in the ground. Verify and annotate if no gas, water, remote heat or other pipeline are crossing the compound above or in the ground.
Estimate the risk of theft or vandalism on the measurement equipment. Give an estimation of a safety guard or similar is required to watch the equipment.

See section „Fehler! Verweisquelle konnte nicht gefunden werden.“ above.

**Detailed description of checklist criteria:**

A site with a minimum extension of $10 \times 10$ m$^2$ is required for the collocation of the meteorological measurement equipment, complying with the characteristics and criteria listed in the following.

The site suitable for collocation of a meteorological station needs to have a firm ground in order to enable a secure fixation of the equipment on the ground, e.g. by ground anchors and guying ropes.

Annotate here if the ground consists of firm and naturally grown soil or artificially (by man) filled soil, if it consists of bedrock, firm soil, loose soil or sand.

Annotate here if the site is approximately horizontally levelled and flat.

Annotate here if it is possible and permitted to lay small foundations (4-5 foundations each approximately $1 \times 1$ m$^2$ and ~0.3 m deep).

Describe any object which exceeds 2 m height in the closer environment of the site and which might shade the measurement equipment on the site from direct sun at any time of the year or which obstructs parts of the sky dome. Describe in detail at least all such objects within 30 m distance as well as bigger objects up to at least 200 m distance from the site. As the sun at sun rise and sun set approaches the horizon in East and West direction ($\pm 30$ degrees depending on season), obstructions in these directions are of particular importance. Add sketches of the site environments where possible. Possible obstructing objects are: mountains, hills, buildings, skyscrapers, houses, industrial or commercial buildings, warehouses, churches/mosques or similar buildings (for religious or cultural activities), walls, bridges, towers, chimneys, wind energy plants, transmission masts, power poles, other poles or rods, cranes, street lights, greenhouses, trees, bushes, shrubberies, any other higher vegetation, or similar. Moreover, the view from the site towards the horizon should be documented by 360° photographs (see corresponding description) or a short movie taken from the site, starting in direction to the North over East, South, and West to North direction again.