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.
ESMAP – Renewable Energy Resource Mapping Initiative

- Solar Resource Mapping for Pakistan –

Site evaluation report:
Peshawar, Pakistan Meteorological Department

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Contents

1 Executive Summary ........................................................................................................... 4
2 Procedure and tasks of the site visit .................................................................................. 4
3 Site visit results .................................................................................................................. 5
   3.1 Overview, description of the site and surroundings .................................................... 5
   3.2 Local support, maintenance staff and future hardware use ........................................ 6
   3.3 Site 1 (roof top on southernmost building) .............................................................. 7
       3.3.1 Coordinates ...................................................................................................... 7
       3.3.2 Checklist for evaluation of the situation of and at the site ................................ 7
       3.3.3 Shadings and Reflections ................................................................................... 9
   3.4 Site 2 (roof top on middle building) .......................................................................... 13
       3.4.1 Coordinates ..................................................................................................... 13
       3.4.2 Checklist for evaluation of the situation of and at the site ................................. 13
       3.4.3 Shadings and Reflections ................................................................................... 14
   3.5 Site 3 (roof top on northernmost building) .............................................................. 17
       3.5.1 Coordinates ..................................................................................................... 17
       3.5.2 Checklist for evaluation of the situation of and at the site ................................ 17
       3.5.3 Shadings and Reflections ................................................................................... 17
4 Conclusion ......................................................................................................................... 21
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 Peshawar on August 06, 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.

Three different sites have been examined on the campus, each on the roof of different buildings of the PMD location.

Although the shading profile is not optimal, site 3 is recommended for the installation of a Tier2 meteorological station (CSP Services MDI automatic weather station) because the site has a high importance for the satellite model validation.

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

![Location overview (Google Maps View)](image1)

![Aerial View (Google Earth View)](image2)

The PMD office in Peshawar is located in the northwest of the city. To its south and east, the town center of Peshawar is located with dense population and settlement. To its west, a district with larger government buildings surrounded by greens starts, and to the north there is a golf club.
Peshawar, the capital of Khyber Pakhtunkhwa province, is located on the eastern exit of the Chaiber pass over the Spin Ghar mountain range and is crossed by the Kabul river and several small tributaries, one of which is located about 2 km to the North of the site. The Swat river is coming from the mountains north of the city and joins the Kabul river 15 km northeast of Peshawar. The mountains are sheltering the city to the west, north (30 km distance) and south (25 km distance). To the east there is mostly flat terrain for about 100 km until the Tarbela dam and lake on the Indus river. The two large rivers unite about 55 km east of the city.

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

- Mr. Syed Mushtaq Ali Shah
  Director - Regional Meteorological Center, Peshawar
  +92 333 5041282
3.3 Site 1 (roof top on southernmost building)

3.3.1 Coordinates

N 34.0147° E 71.5661°, altitude 325 m above mean sea level

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

![Figure 3: View from Site 1 to the North](image1)

![Figure 4: View from Site 1 to the South](image2)

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&lt;sup&gt;l&lt;/sup&gt;</td>
<td></td>
<td>Site 1: Rooftop</td>
</tr>
<tr>
<td>Minimum area 10 x 10 m²</td>
<td>No</td>
<td>Site 2: Rooftop</td>
</tr>
<tr>
<td>Site 3: Rooftop</td>
<td></td>
<td>Site 3: Rooftop</td>
</tr>
<tr>
<td>Surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm natural ground&lt;sup&gt;ii&lt;/sup&gt;</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Ground type&lt;sup&gt;iii&lt;/sup&gt;</td>
<td>Concrete</td>
<td></td>
</tr>
<tr>
<td>Horizontally levelled&lt;sup&gt;iv&lt;/sup&gt;</td>
<td>Yes</td>
<td>Casting Blocks are preferred</td>
</tr>
<tr>
<td>Excavation for foundations possible&lt;sup&gt;v&lt;/sup&gt;</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Fencing of the site possible&lt;sup&gt;vi&lt;/sup&gt;</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>No drifting sand/snow&lt;sup&gt;vii&lt;/sup&gt;</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>No flooding possible&lt;sup&gt;viii&lt;/sup&gt;</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Surroundings</td>
<td>Yes/No</td>
<td>Details</td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td>--------</td>
<td>----------------------------------------------</td>
</tr>
<tr>
<td>Obstructions</td>
<td></td>
<td>If yes, note direction, distance and approx. height</td>
</tr>
<tr>
<td>Reflections or light sources</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Industrial areas or power plants</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Sources of smoke or vapor</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Quarry or mine</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Main road, dirt road, track</td>
<td>Paved Roads</td>
<td></td>
</tr>
<tr>
<td>Airports</td>
<td>No</td>
<td>Quite far from nearest airport</td>
</tr>
<tr>
<td>Settlements, towns, city</td>
<td>Yes</td>
<td>Urban Area</td>
</tr>
<tr>
<td>Agricultural area</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Swamp, lake, river, ocean</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Sand dunes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Animal populations</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Occurrence of snowfall</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Temperatures below freezing point</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Accessibility</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>GSM coverage</td>
<td>All 5 providers</td>
<td>2G network available</td>
</tr>
<tr>
<td>Grid power</td>
<td>Frequent power outages.</td>
<td>Electricity available</td>
</tr>
<tr>
<td>Land use rights</td>
<td>Approval to be given by PMD</td>
<td>Permit available</td>
</tr>
<tr>
<td>Operation permit</td>
<td>Approval to be given by PMD</td>
<td>Permit available</td>
</tr>
<tr>
<td>Security</td>
<td>Some electrical cables quite close to Site 1</td>
<td>No underground or overhead electrical lines, pipelines or similar</td>
</tr>
<tr>
<td>Measures against theft or vandalism required?</td>
<td>Site 1 and Site 2 are within the office premises.</td>
<td>No</td>
</tr>
</tbody>
</table>
Site 3 is on top of the staff hostel building so fencing will be required.

| 360° photographs | Take 360° photographs or panoramic photo, indicate North direction³³ⅱ | Yes | Tripod bag denotes the north direction

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; safety of the equipment against human or natural influences is given on the guarded complex. 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
From the panoramic view, it is visible that many obstacles such as trees, power lines and structures on the horizon are blocking the sun. The impact is further analyzed in the following paragraphs.

**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 months from November to February, the sensor is permanently shaded.

Figure 6: Shading Table for Sun Elevations >0°
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 and is only slightly reduced in the months of March to October in the evening hours.
**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.

![Maximum shading impact on DNI measurements at clear sky due to horizon obstructions](chart)

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

From the figure, it is clearly visible that shadings have an extreme impact throughout several months.

![Percentage of Time influenced by direct Shading vs Reduction of BirdDNI due to direct Shading](chart)

**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 16 % of the time is affected by direct shading. 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 30.6 %.

**Diffuse Shading and Reflections**

The multitude of obstacles, especially the tree standing very close to the South, will probably have some shading effect even on the diffuse radiation.

Reflections of any mentionable quantity are not to be expected since no highly reflective surface above sensor height can be identified.

### 3.4 Site 2 (roof top on middle building)

#### 3.4.1 Coordinates

N 34.0151° E 71.5660°, altitude 325 m above mean sea level

Site 2 is located on the roof of another building of the PMD office complex.

![Figure 10: View from Site 2 to the North](image1)

![Figure 11: View from Site 2 to the South](image2)

#### 3.4.2 Checklist for evaluation of the situation of and at the site

The checklist does not differ from the checklist for site 1.
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 many trees are blocking the sun especially in the east in the area where the sun rises in the morning, and in smaller quantity also near sunset. The impact is further analyzed in the following paragraphs.

Shading Table for Sun Elevations >0°

Figure 13: Shading Table for Sun Elevations >0°

Figure 13 shows the shading table throughout the year. It becomes clear that throughout the year, the sensor suffers shading in the morning (up to 2 hours after sunrise) and in the evening (up to about 1.5 hours before sunset).
Figure 14: Shading Table for Sun Elevations >5°

Figure 14 shows the shading table after excluding Sun Elevations smaller than 5° above horizon. 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 in the morning still occurs but is limited in duration, and is almost removed in the evening hours except of the months May and August (and a few surrounding days).
**Direct Shading Impact**

From Figure 15, it is clearly visible that shadings have a sizeable impact throughout several months.

**Figure 15: Shading Impact on BirdDNI for Sun Elevations >5°**

Figure 15 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 4.3 % of the time is affected by direct shading. 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 6.6 %.

**Figure 16: Shading Impact for Sun Elevations >5°**
Diffuse Shading and Reflections
Effects of diffuse shading and reflections are expected to be minimal and can be ignored.

3.5 Site 3 (roof top on northernmost building)

3.5.1 Coordinates
N 34.0154° E 71.5661°, altitude 325 m above mean sea level
Site 2 is located on the roof of the northernmost building of the PMD office complex (which could be seen to the north at site 1).

Figure 17: View from Site 3 to the North
Figure 18: View from Site 3 to the South

3.5.2 Checklist for evaluation of the situation of and at the site
The checklist does not differ from the checklist for site 1.

3.5.3 Shadings and Reflections
Panoramic View
Figure 19: 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 some trees and the top of the staircase are blocking the sun in the east in the area where the sun rises in the morning, and in smaller quantity also near sunset. The impact is further analyzed in the following paragraphs.

Shading Table for Sun Elevations >0°

Figure 20: Shading Table for Sun Elevations >0°

Figure 20 shows the shading table throughout the year. It becomes clear that almost throughout the entire year, the sensor suffers shading in the morning (up to 2 hours after sunrise) and in the evening (up to about 1 hour before sunset).
Figure 14 shows the shading table after excluding Sun Elevations smaller than 5° above horizon. 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 in the morning still occurs but is reduced in duration, and is almost removed in the evening hours except of the months March and October (and a few days in May and August).
Direct Shading Impact

Figure 22: Shading Impact on BirdDNI for Sun Elevations >5°

From Figure 15, it is clearly visible that shadings have a sizeable impact throughout several months.

Figure 23: Shading Impact for Sun Elevations >5°

Figure 23 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 3% of the time is affected by direct shading. 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 4%.
**Diffuse Shading and Reflections**

Effects of diffuse shading and reflections are expected to be minimal and can be ignored.

### 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 atmospherical 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 1 is out of question due to the many shadings. Site 2 and 3 have similar shading profiles with an impact of obstacles especially in the morning and to a lower extend in the evening as well. The total shading is lowest at site 3.

Since there are currently no alternatives to the PMD site in the Peshawar area and measurements in this area are considered as highly relevant to the satellite model validation, site 3 is therefore recommended for the installation of a Tier 2 meteorological station, with the additional recommendation to elevate the sensor as high as possible (while still allowing easy maintenance access) in order to reduce the shadings. However, the shadings are acceptable since their occurrence can be determined beforehand and the affected periods can be excluded from model validation easily.

Since the site 2 is located on the office staff hostel building, the station should be protected with a fence or barrier.
Detailed description of checklist criteria:

i. A site with a minimum extension of 10 × 10 m² 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 × 1 m² 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, 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.

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.