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Palestine Polytechnic University

College of Engineering & Technology

Mechanical Engineering Department

Graduation Project

Assessing Solar and Wind Energy Resource in Palestine

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Acknowledgment

As we finished our graduation project we thank everybody who has helped us to complete this work.

First we want to thank our supervisor Dr.Imad Al.Khatib who gave us the support we need and helped us completing this work as needed.

Abstract

Assessing Solar and Wind Energy Resource in Palestine

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The project implemented concerns building a tool for assessing the potential of renewable energy resources in Palestine; namely wind and solar radiation energies. It depends on building gridded maps with energy resources parameters overlying the maps corresponding to any location over the chosen geographic domain (Palestine). The overlying meteorological parameters; such as average air temperature (yearly and seasonally), the relative humidity, the wind speed and direction and the precipitations are easily presented over the domain. In addition energy parameters that describe the energy potential are also presented. This includes the wind power density and the solar insolations over different collector tilt angles. Meteorological variables were collected from the MTEONORM package and then homogenized over the chosen domain. Data from the Palestinian Meteorological Department were unfortunately not accessible. The inaccessibility of the Palestinian data has shortcoming on the results. Although the results represent a degree of relevancy in some areas over the domain, but the unavailability of the national data has caused irrelevancy in some other areas.

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Chapter One

Introduction

1.1 Objectives
1.2 Methodology
1.3 Time Table

Energy is the most important sources for life and development. The last two centuries witnessed an escalating use of energy resources, in particular the hydrocarbons (fossil) especially during the second half of the last century. The major global problem identified as the climate change and the global warming is mainly due to the excessive burning of fossil fuel. The solutions proposed are ranging from actions for reducing the greenhouse gasses emissions and the use of alternative energy sources, including the renewable enrgy sources. The renewable energy sources are promising in several areas around the globe and in particular those locations within the solar radiation belt that extend to 40° North from tropical line. Palestine is located within this belt and has huge potential of renewable energy, both solar and wind. The following is an assessment to the solar and wind energy resources potential performed on solar and wind atlas maps. The maps highlight the distribution of solar and wind parameters and they can be used by engineers, researchers and decision makers to plan for the best utilization of solar and wind energy resources.

1.1 Objectives

The objective is to assess the potential of solar and wind energies different systems and best areas for installing proper systems. in addition to determining the climatologic characteristics and data for Palestine that may help improving weather information and forecasting.

1.2 Methodology:

Historical climatologic data for the last 40 years were seeked in the first place for a desired domain shown in figure(A) below. The domain comprises Palestine, part of the Mediterranean and Red seas, part of Lebanon, Syria, Jordan and Egypt. It extends 29-34 degrees north and 34-36 east. The historical climatological data identified for the study are:

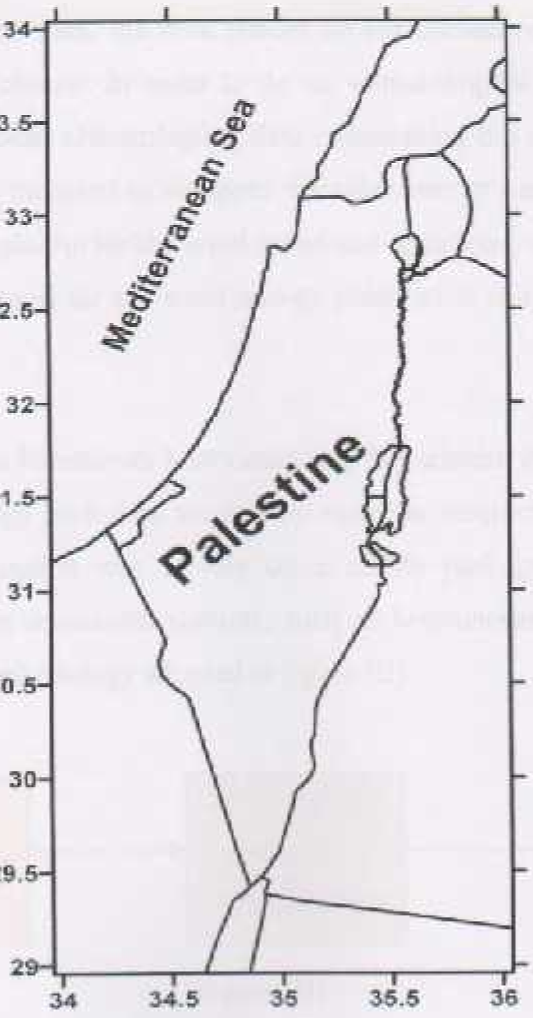


Figure (A)

- The monthly averaged air temperatures that include: the maximum, the minimum and the mean values in C°,

- The monthly mean solar radiation in W/m^2.

- The wind speed.

-The Wind direction.

-The relative humidity.

In order to produce atlas data, the data should be representative to the relevant grids overlaying the domain chosen. In order to do so, climatological data are identified on each station grid. The mean climatological data representing the domain and distributed on the gridded area are the used to compute the solar energy parameters for collectors tilted on different tilt angle. As for the wind speed and directions, the wind power density (WPD), which is a measure for the wind energy potential is computed for each station (grid).

It is unfortunate that the Palestinian Meteorological Department did not provide us with the relevant data although such data are usually open for research institutions and even for public. The other option was to rely on available packages that have recorded climatological data from associated stations, such as Meteonorm. The following block diagram illustrate the methodology adopted in figure (B).

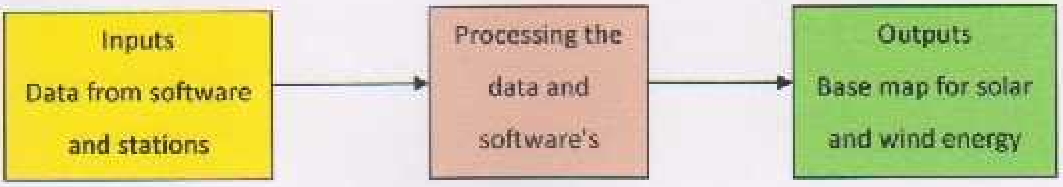


Figure (B)

The blocks depict the methodology adopted in which input data from METEONORM package software were downloaded for already identified meteorological stations within the domain. The software has also the capability of producing meteorological stations by interpolating data from real meteorological stations surrounding close points (chosen station). Three real stations are enough to perform a krigging interpolation and produce another station records. METONORM capability allowed for 60% of the gridded domain to be covered. Again, the refusal of the Palestinian meteorological department to provide the national data resulted in losing not less than 30% of the needed gridded coordinates.

In the second block collected data were organized in excel pivot table format for processing. The processing of the data allowed grouping seasonal data and calculating the averages and energy parameters. Outputs were organized in spread sheet format for post processing and for graphical presentation.

The last block of the process entails the processing of the outputted spreadsheet data using the graphical software surfer 8.0. In this process the base map of Palestine was created and gridded. Same grids were taken to build relevant spreadsheet data and each grid point correspond to meteorological station. A total of 1526 stations were created and for each station relevant calculations were made. The output were presented using Surfer8.0. and representative resources maps were created and presented as will be seen in the successive pages.

1.3 Time Table

Table 1.1: Project time-schedule for first semester

Process	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Choosing group	■														
Project determination		■	■												
Understanding project concept			■	■											
Searching for Software's					■	■									
Getting started With software's						■	■	■	■						
Data collection								■	■	■	■	■			
Writing documentation							■	■	■	■	■	■	■	■	■

Searching software's : from internet and supervisor Dr. Imad Khatib.

Data collection :generated from software's and climatologic stations with using excel program .

Table 1.2: Project time-schedule for second semester

Process	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Climate data Collection	■	■	■	■	■										
Solar radiation and wind energy data calculation			■	■	■	■	■								
Using golden software to build maps						■	■	■	■	■	■	■			
Data analysis and relevant formatting											■	■	■		
Maps building												■	■	■	■
Writing project document							■	■	■	■	■	■	■	■	■

Solar radiation and wind energy data calculation : all data and equation entered to Excel program to take values of Solar radiation .

The Meteonorm program and Golden surfer (8) its free from internet with help Dr.imad khatib

Chapter Two

Renewable Energy

2.1 Wind Energy
2.2 Solar Energy
2.3 Solar and Wind Energy Assessment
2.4 Solar and Wind Energy Resource Assessment (SWERA)

Renewable energy

"Since the Industrial Revolution, humans have used fossil fuels as their primary energy source. However, the amount of fossil fuels on the earth is limited, and their use has caused unprecedented changes to the global ecological environment and climate. Gases from burning fossil fuels can build up in the atmosphere, becoming thicker and thicker to produce greenhouse effects (The greenhouse effect is the rise in temperature that the Earth experiences because certain gases in the atmosphere trap energy from the sun. Without these gases, heat would escape back into space and Earth's because of how they warm our world) such as rising global temperature and sea level. These effects will dramatically alter our living environment. Fortunately, humans are becoming more conscious of environmental protection, and are seeking new energy sources that cause less pollution and do not threaten the environment"[1]. One of the potential solutions to the environmental threats is the utilization of renewable energy sources.

" The Renewable energy is energy that is produced from sources that replenish themselves naturally. This includes wind, sunlight (solar), landfill and agricultural waste (biomass), and the heat of the earth (geothermal). These renewable sources of electricity have less impact on the environment than traditional methods of electricity generation, which includes burning fossil fuels such as coal, oil and natural gas.

Renewable energy has a much lower impact on the environment than traditional methods of electricity generation. It produces lower levels of air pollutants, wastewater, smog and acid rain, and it can help reduce greenhouse gas emissions. The renewable energy, it is possible to help protect the environment by offsetting the need for more fossil fuel generation. In addition the renewable energy can help reduce nation's reliance on fossil fuels"[2]

2.1 Wind Energy

"Wind energy has been used since the earliest civilization to grind grain, pump water from deep wells, and power sailboats

Figure (2.1): Wind Energy Sources

In recent decades, the industry has been perfecting the wind turbine to convert the power of the wind into electricity. The wind turbine has many advantages that make it an attractive energy source, especially in parts of the world where the transmission infrastructure is not fully developed. It is modular and can be installed relatively quickly, so it is easy to match electricity supply and demand. The fuel – the wind – is free and plentiful, which eliminates or reduces the need to purchase, ship, and store expensive fuels. It is flexible – with the power generated, households use can use appliances, such as lighting and refrigeration, schools can use computers and televisions, and industries can access a reliable power source. Perhaps most importantly, the generator does not produce any harmful emissions in the process of generating the electricity, unlike many other generation sources.

The use of renewable to provide power to remote villages has had a mixed record in the past because maintenance was costly and replacement parts difficult to obtain. However, due to research on very low-maintenance designs, small wind turbines are once again gaining popularity as an economical way to bring the benefits of power production to homes, villages, and industries that may be remote from an established grid or wish to operate without burning fossil fuels. Large wind turbines can be price competitive with any other form of generating technology in good wind resource areas.

Wind energy conversion systems are available in a wide range of sizes and can fit almost any application where power is needed.

2.1.1 Wind Power Basics

When designing a wind power system, it is crucial to understand the electricity load and the available resources.

• Demand

Estimating the electricity demand means determining the maximum power to be consumed as well as the purpose to which the electricity will be put.

• Equipment selection

In addition to the wind resource and the planned usage, the size and type of the equipment greatly affects the power output.

• Resource Assessment

Wind resource assessment is also important to a successful project. Small differences in wind speed can mean great differences in power output.

2.1.2 Wind power Applications

Water Pumping

Mechanical wind water pumping machines have been used to pump water from wells for centuries. The technology of modern mechanical water pumpers is relatively simple, the maintenance requirements are modest, and the replacement parts are not difficult to obtain Wind electric pumping systems allow greater sitting flexibility, higher efficiency of wind energy conversion, increased water output, increased versatility in use of output power, and decreased maintenance and life-cycle costs.

Systems for Community Centers, Schools, and Health Clinics

A larger system can provide power to a centralized community center, health clinic, or school. A power system for a health center can enable the storage of vaccines and radio communication for emergency calls. A power system for a school can provide electricity for computers and educational television, video, and radio. Community centers often find that, in addition to the benefits of the power, such as lighting and cooling, the "waste energy" can be used to charge batteries or make ice for sale to households.

Industrial Applications

The number of dedicated industrial applications for wind power continues to grow. Small wind power systems are ideal for applications where storing and shipping fuel is uneconomical or impossible.

Wind power is currently being used for telecommunications, radar pipeline control, navigational aids, weather stations/seismic monitoring, air-traffic control" [3].

2.2 Solar Energy

"Solar energy is the light and radiant heat from the Sun that influences Earth's climate and weather and sustains life. Solar power is sometimes used as a synonym for solar energy or more specifically to refer to electricity generated from solar radiation, since ancient times solar energy has been harnessed for human use through a range of technologies.

Figure (2.2): Solar Energy

Solar radiation along with secondary solar resources such as wind and wave power, hydroelectricity and biomass account for most of the available flow of renewable energy on Earth.

Solar energy technologies can provide electrical generation by heat engine or photovoltaic means, space heating and cooling in active and passive solar buildings; potable water via distillation and disinfection, day lighting, hot water, thermal energy for cooking, and high temperature process heat for industrial purposes." [4]

2.2.1 Solar Power Applications

Industrial Applications

"For many years, Solar Energy has been the power supply of choice for Industrial applications, where power is required at remote locations. This means in these applications that solar power is economic, without subsidy. Most systems in individual uses require a few kilowatts of power.

Solar energy is also frequently used on transportation signaling e.g. offshore navigation buoys, lighthouses, aircraft warning lights on pylons or structures, and increasingly in road traffic warning signals, well-heads, and bridges or other structures. As before, for larger electrical loads it can be cost effective to configure a hybrid power system that links the (Photovoltaic (PV) panels is a system that uses solar energy to generate electricity at a lower cost and is working to attract sunlight through the cells topped lenses intensify rays to benefit as much, most of which then converts it to electrical energy is stored in special batteries for use at the time and the proper amount) with small diesel generators.

Water Pumping, lighting, heating in the Developing World

Apart from off-grid homes, other remote buildings such as schools, community halls, and clinics can all benefit from electrification with Solar Energy. This can power TV, video, telephony and a range of refrigeration equipment, which is available to meet World Health Organization standards for vaccine refrigeration, for instance. Rather than base Solar power generation on individual dwellings, it is also possible to configure central village power plants that can either power homes via a local wired network, or act as a battery charging station where members of the community can bring batteries to be recharged.

PV Systems can be used to pump water in remote areas e.g. as part of a portable water supply system. Specialized solar water pumps are designed for submersible use (in a borehole) or to float on open water. Usually, the ability to store water in a tank means that battery power storage is unnecessary. Large-scale desalination plants can also be PV powered. Larger off-grid systems can be constructed to power larger and more sophisticated electrical loads by using an array of PV modules and having more battery storage capacity.

To meet the largest power requirements in an off-grid location, the PV system is sometimes best configured with a small diesel generator. This means that the PV system no longer has to be sized to cope with the worst sunlight conditions available during the year. The diesel generator can then provide the back-up power, but its use is minimized during the rest of the year by the PV system, so fuel and maintenance costs are kept low.

Solar energy can also power area lighting to enable more outdoor activities after dark or improve security, and to illuminate signs or advertising boards"[5].

2.3 Solar and Wind Energy Assessment

In order that practical assessment of the potential utilization of either of solar and wind energy or both, recourse maps are crucially needed.

The maps would easily give indications to any scientist or decision maker to potential side with solar or wind energy and in addition help assessing possible best technology for energy conversion, community served and at the same time the feasibility ; technically and economically, of any development plan .

The project presented here describes the method and its outcomes, the method utilizes the recorded meteorological values by a number of meteorological stations covering Palestine. The recorded values are then distributed on the girded base map and used to compute relevant energy parameter that are required for any assessment.

The project presented here is based on an international recognized assessment program called SWERA (Solar and Wind Energy Resources maps, Program provides easy access to credible renewable energy data to stimulate investment in, and development of, renewable energy technologies) that was implemented for several regions.

2.4 Solar and Wind Energy Resource Assessment (SWERA)

"Solar, wind, geothermal, biomass, hydro and wave energy resources have the potential to meet several times the world's present and future energy demands. The catch is that these resources are not evenly distributed, and can vary greatly within even small geographic regions.

Quantifying the renewable energy resources of a region is necessary before they can be harnessed. Without timely and reliable assessments of the size and scale of a particular renewable energy resource, investors cannot determine whether a project will be viable, especially their potential return on investment.

High quality assessments of renewable energy resources also allow national and state energy agencies to establish long-term and scientifically robust sustainable energy options and policies, including plans and policies by environmental agencies to reduce greenhouse gas emissions.

Developing countries, however, are generally not so fortunate. Weak national institutions and the lack of resources means the potential to expand their economies with clean energy is severely restricted.

The Solar and Wind Energy Resource Assessment project(SWERA) was launched in 2001 as collaboration between 25 international institutions to develop the information tools needed to stimulate renewable energy projects. SWERA initially focused on major areas of thirteen developing countries across Latin America, the Caribbean, Africa and Asia, and was supported by the Global Environment Facility (GEF), with additional support by the United Nations Environment Program (UNEP), and the US National Aeronautic and Space Administration (NASA).

SWERA took the first step for creating indigenous renewable enterprises by producing maps of each country's solar and wind resources. Scientists at SWERA institutions, however, added new satellite data to the available terrestrial weather data.

To produce solar maps, scientists used weather satellite imagery to infer a country's resource. Wind maps were produced from high-resolution imagery and high-quality numerical models of wind flow over complex terrain. Creating maps with sufficient quality to be used for large-scale renewable energy applications was a principle SWERA goal, but another important accomplishment was creating a standard product from a range of institutions and techniques, combining solar and wind data from many different measuring instruments and techniques.

One of SWERA's strengths is making solar and wind data compatible with geographic information systems (GIS).

SWERA has produced a range of solar and wind datasets and maps at acceptable resolutions. The renewable energy information provided through SWERA includes:

-Maps of wind and solar energy potential

-Atlases of solar and wind energy resources" [6].

Chapter Three

Tools and Means

3.1 Software Tools

3.1.1. METEONORM

3.1.2 Golden Software (Surfer 8)

3.2 Solar Radiation Calculations

3.3 Method for Interpolating Climatological Data

3.1 Software Tools

Two main software packages were used. The first is database software that represent meteorological stations associated with the software and located all over the world. The second software is the golden surfer used professionally to present meteorological data distributed over geographic domains as overlays. Both software are used together in this context.

3.1.1. METEONORM

"It is a comprehensive meteorological reference, incorporating a catalogue of meteorological data and calculation procedures for solar applications and system design at any desired location in the world. It is based on over 20 years of historical data collection in the process of developing meteorological databases for energy applications. The software addresses engineers, architects, teachers, planners and those interested in solar energy and climatology.

The associated stations that have their historical data attached and updated in the software are more than 7'700 weather stations, with measured parameters of global radiation, temperature, humidity, precipitation, days with precipitation, wind speed and direction, sunshine duration, in addition to updated global radiation database for period (1981-2008), also it uses satellite data for areas with low density of weather stations, beside the Inclusion of climate change forecast.

The software has built in interpolation algorithms based on several interpolation methodologies. Data can be imported by users and can be obtained in different formats and in five languages; English, French, German, Italian and Spanish.

Data Import:

The software offers 28 different predefined output formats that may be used for the calculation of hourly as well as monthly climatological parameters values and can then be converted to ASCII formats" [7].

The following figures are examples of the software interface.

Example :

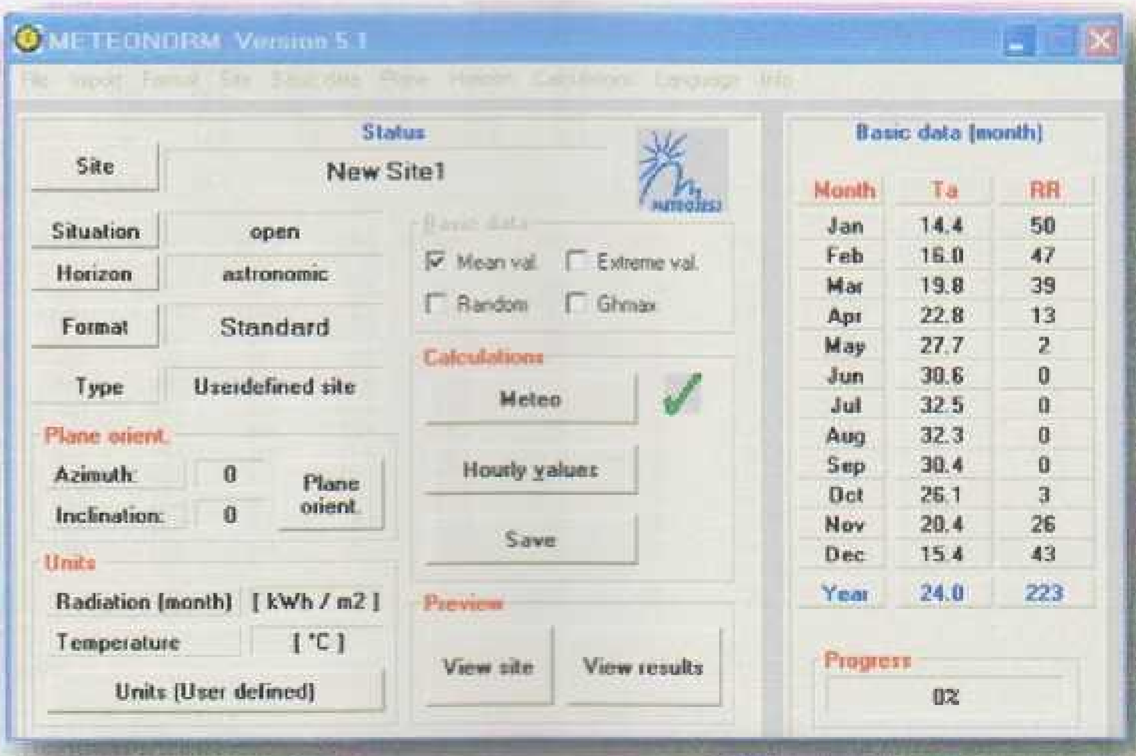


Figure (3.1): Meteonorm program

Calculation (hour) 10. 06. 2009 / 15:02

METEONORM Version 5.1

Site:	New Site1		
Situation:	open		
Horizon:	astronomic		
Type	Userdefined site	Format	METEO

Month	Ta	Ta min	Ta dmin	Ta dmax	Ta max	RH
Jan	14.4	2.7	8.7	19.9	24.4	64
Feb	16.0	4.3	10.3	21.2	25.8	56
Mar	19.8	8.4	13.8	26.2	31.0	51
Apr	22.8	9.6	18.0	28.5	34.6	47
May	27.7	13.9	20.8	33.9	39.8	42
Jun	30.6	17.4	23.0	36.2	40.8	43
Jul	32.5	18.1	25.3	39.1	42.9	43
Aug	32.3	19.0	25.7	38.1	41.5	48
Sep	30.4	15.5	23.9	36.6	40.2	49
Oct	26.1	15.2	20.6	31.4	35.5	54
Nov	20.4	8.8	14.2	25.9	32.3	57
Dec	16.4	3.6	9.7	21.2	26.2	63
Year	24.0					52

Month	H_Gh	SDm	SDd	SD astr	RR	RD	FF	DD
Jan	108	197	6.4	10.2	50	6	1.5	90
Feb	111	190	7.1	11.0	47	5	1.6	90
Mar	165	240	7.7	11.9	39	4	1.8	90
Apr	190	261	8.7	12.8	13	2	1.8	338
May	229	326	10.6	13.6	2	1	1.7	338
Jun	243	368	12.3	14.0	0	0	1.7	315
Jul	250	385	12.4	13.8	0	0	1.7	315
Aug	228	365	11.8	13.1	0	0	1.5	315
Sep	194	313	10.4	12.2	0	0	1.4	338
Oct	160	281	9.1	11.3	3	1	1.4	338
Nov	118	232	7.7	10.4	26	3	1.5	90
Dec	96	195	6.3	10.0	43	5	1.4	90
Year	2081	3352	9.0		223	26	1.6	1

Legend:

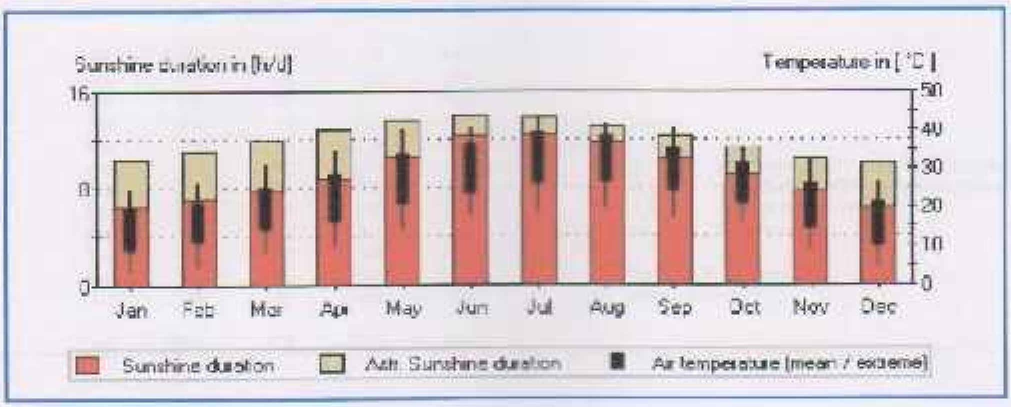
Ta:	Air temperature	RH:	Relative humidity
Ta min:	10 y minimum (approx.)	Ta max:	10 y maximum (approx.)
Ta dmin:	Mean daily minimum Ta	Ta dmax:	Mean daily maximum Ta
SD:	Sunshine duration	RR:	Precipitation
RD:	Days with precipitation	FF:	Wind speed
SD astr.:	Sunshine duration, astronomic	DD:	Wind direction
H_Gh:	Irradiation of global radiation horizontal		

Temperature in [°C]
Wind speed in [m/s]
Sunshine duration in [h/day]
Radiation in [kWh/m²]

Calculation (hour) 10. 06. 2009 / 15:02

METEONORM Version 5.1

New Site1



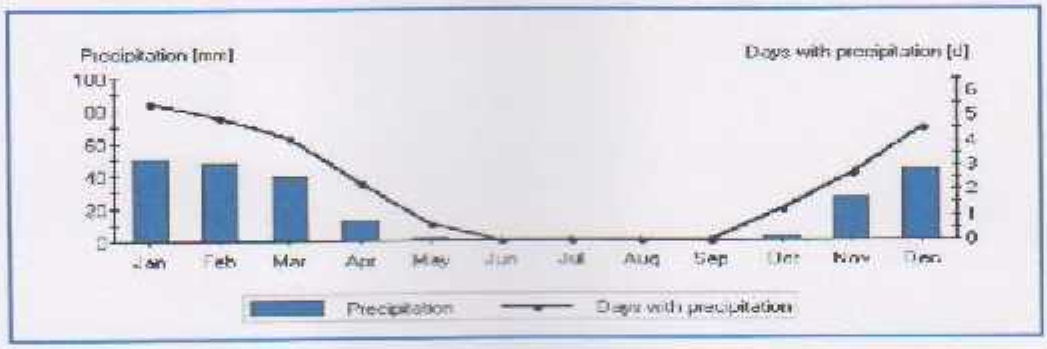


Figure (3.2): Meteonorm (monthly values diagram)

Calculation (hour) 10. 06. 2009 / 15:11

METEONORM Version 5.1

Site:	New Site1		
Situation:	open		
Horizon:	astronomic		
Azimuth:	0	Inclination:	0
Type	Userdefined site	Format	Standard

Month	H_Gh	H_Dh	H_Bn	Ta
Jan	103	40	130	14.4
Feb	111	44	123	17.0
Mar	165	60	180	18.8
Apr	190	74	188	22.8
May	229	73	218	27.7
Jun	248	60	253	30.6
Jul	250	57	262	32.5
Aug	228	59	239	32.3
Sep	194	47	221	30.4
Oct	158	43	199	26.1
Nov	118	39	161	20.4
Dec	98	37	131	15.4
Year	2001	828	2278	24.0

Legend:

H_Gh: Irradiation of global radiation horizontal
H_Dh: Irradiation of diffuse radiation horizontal
H_Bn: Irradiation of beam
Ta: Air temperature

Radiation in [kWh/m²]
Temperature in [°C]

3.1.2 Golden Software (Surfer 8)

"The Surfer is a contouring and 3D surface mapping program that can easily convert data into contour, surface, wireframe, vector, image, shaded relief, and post maps overlayed on base maps. (Figure 3.3) below shows the software interface.

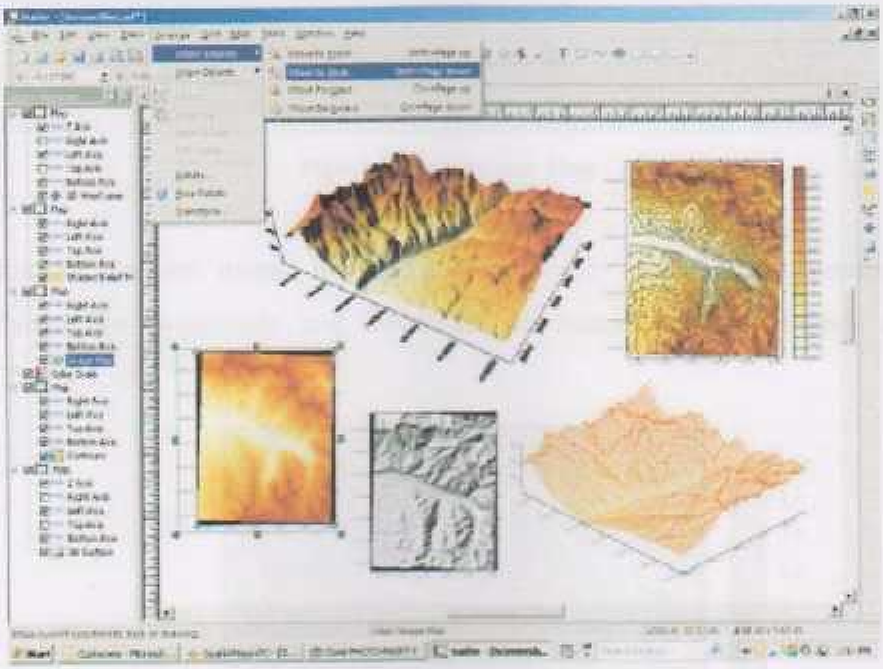


Figure (3.3): Golden software (Surfer 8)

Surfer contour maps could be easily customize with specific features that may illustrate the distributed parameters over the geographic areas.

An example map produced by the software is shown in (Figure 3.4) below.

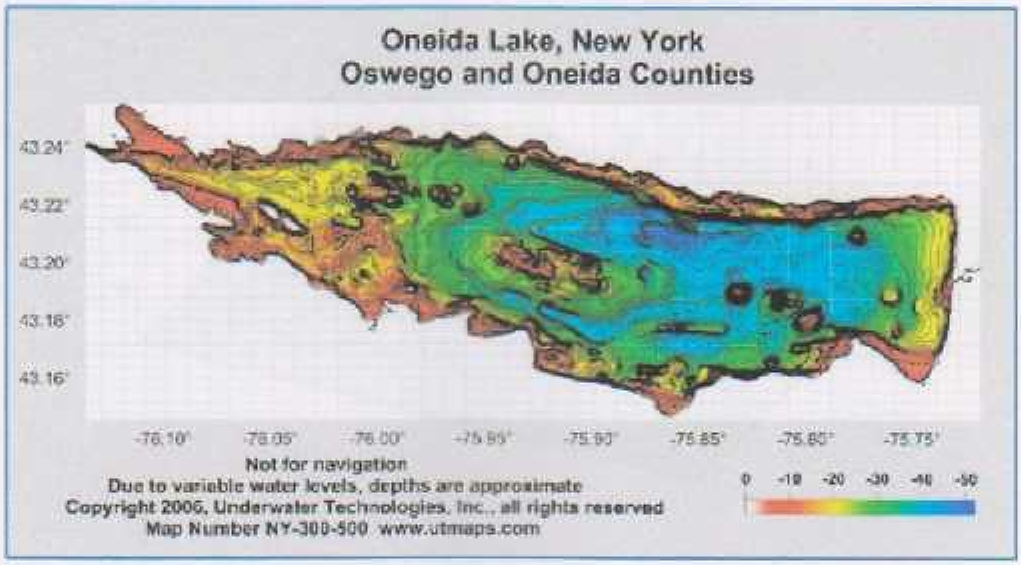
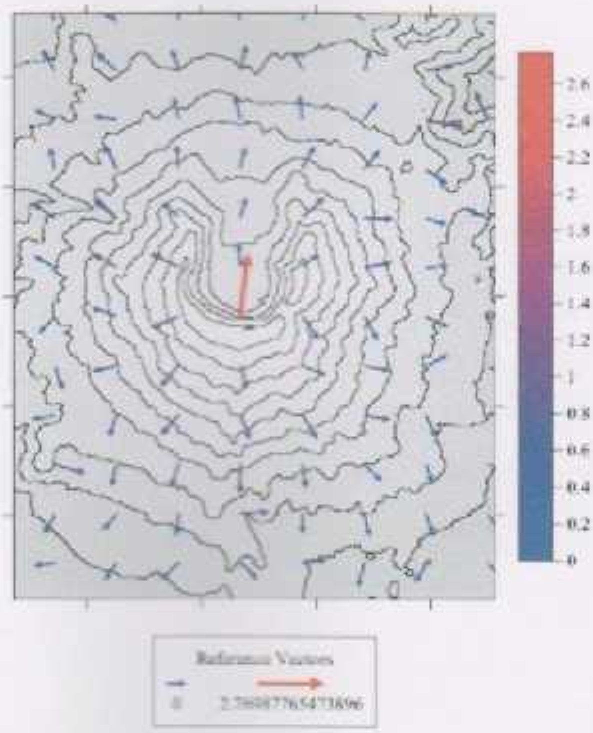


Figure (3.4): Contour Map

In addition to contour maps, the software has the capability to produce vector maps presents the magnitude and directions of vectors, such as winds shown in (Figure 3.5 and 3.6)" [8].



Figure(3.5): Vector map

Figure (3.6): Vector map

The capability includes adding multiple map layers to the base map

3.2 Method for Interpolating Climatological Data

The method used in this work is called the Kriging interpolation technicque which is named after the South African mining engineer D. G. Kriging who developed the technique in an attempt to more accurately predict ore reserves. Over the past several decades Kriging has become a fundamental tool in the field of geo-statistics.

Kriging is based on the assumption that the parameter being interpolated can be treated as a regionalized variable. A regionalized variable is intermediate between a truly random variable and a completely deterministic variable in that it varies in a continuous manner from one location to the next and therefore points that are near each other have a certain degree of spatial correlation, but points that are widely separated are statistically independent (Davis, 1986). Kriging is a set of linear regression routines which minimize estimation variance from a predefined covariance model.

3.2.1 Ordinary Kriging

The first step in ordinary kriging is to construct a variogram from the scatter point set to be interpolated. A variogram consists of two parts: an experimental variogram and a model variogram. Suppose that the value to be interpolated is referred to as f. The experimental variogram is found by calculating the variance (g) of each point in the set with respect to each of the other points and plotting the variances versus distance (h) between the points. Several formulas can be used to compute the variance, but it is typically computed as one half the difference in f squared.

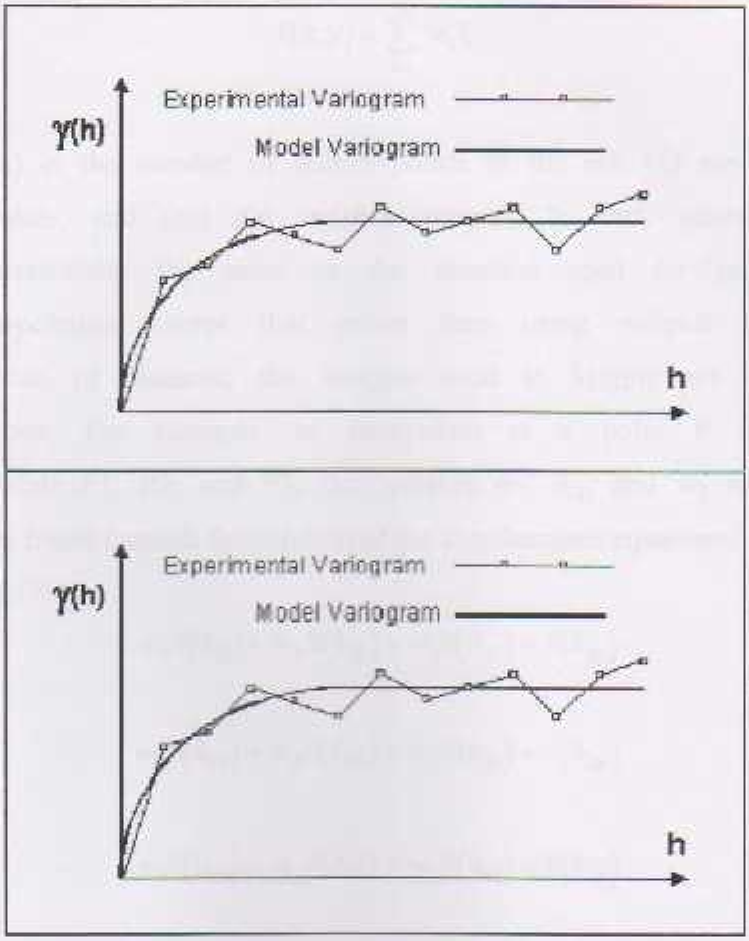


Figure (3.7) Experimental and Model Variogram Used in Kriging

Once the experimental variogram is computed, the next step is to define a model variogram. A model variogram is a simple mathematical function that models the trend in the experimental variogram.

As can be seen in figure (3.7), the shape of the variogram indicates that at small separation distances, the variance in f is small. In other words, points that are close together have similar f values. After a certain level of separation, the variance in the f values becomes somewhat random and the model variogram flattens out to a value corresponding to the average variance.

Once the model variogram is constructed, it is used to compute the weights used in kriging. The basic equation used in ordinary kriging is as follows:

$$F(x,y) = \sum_{i=1}^{n} w_i f_i$$

where (n) is the number of scatter points in the set, (f_i) are the values of the scatter points, and (w_i) are weights assigned to each scatter point. This equation is essentially the same as the equation used for inverse distance weighted interpolation except that rather than using weights based on an arbitrary function of distance, the weights used in kriging are based on the model variogram. For example, to interpolate at a point P based on the surrounding points P1, P2, and P3, the weights w_1, w_2, and w_3 must be found. The weights are found through the solution of the simultaneous equations:

$$w_1 S(d_{11}) + w_2 S(d_{12}) + w_3 S(d_{13}) = S(d_{1p})$$

$$w_1 S(d_{12}) + w_2 S(d_{22}) + w_3 S(d_{23}) = S(d_{2p})$$

$$w_1 S(d_{13}) + w_2 S(d_{23}) + w_3 S(d_{33}) = S(d_{3p})$$

where S(dij) is the model variogram evaluated at a distance equal to the distance between points (i) and (j). For example, S(d1p) is the model variogram evaluated at a distance equal to the separation of points P1 and P.

Chapter Four

Solar and Wind Energy Resources Maps in Palestine

4.1 Solar Energy Maps

- **4.1.1 Solar Insolation maps on Different Tilt Angles**
- **4.1.2 Temperature Maps on Different Seasons**

4.2 Wind Energy Maps

- **4.2.1 Wind Power Density Maps**
- **4.2.2 Wind Speed Maps**

The data that has been imported from the METENORM software has been arranged homogenized over the domain chosen. The homogenization is based on the krigging interpolation method. At this stage, the validation of the METONORM data could not be achieved. This is because data from Palestinian Meteorological Department of the Ministry of Transportation could not be retrieved as they have not yet decided on the bylaws that govern accessing the already recorded climatic data by research institutions. This in turn may affect negatively the precisions of the results.

Scripts for manipulating the homogenized data were then built. The data were formatted to be recognized and read by the analysis and plotting software used, which is the Surfer 8.0 plotting package of the GOLDEN SOFTWARE. Homogenized data of solar radiation were used to compute solar irradiance on tilted areas, simulating solar energy collection applications; such as the popular solar domestic hot water systems. Wind speed and direction were used as well to compute the wind power density, a measure which is used to assess the wind energy conversion applications. Other homogenized climatic parameters such as air temperature, humidity and derived climatic values can easily be represented over the chosen domain.

4.1 Solar Energy Maps

4.1.1 Solar Insolation Maps On Different Tilt Angles

The solar insolation maps that show the magnitude of the received solar energy have been built with different tilt angles: 20°, 40° and 50°.

The following relations show the mathematical equations followed to find the solar insolation by using the different tilt angles

$$\bar{H}_t = \bar{H}\,\bar{R}$$

Where $\bar{H}_t$ the global solar insolation on tilted surface, $\bar{H}$ is the irradiation of global radiation horizontal and $\bar{R}$ is the total radiation tilt factor.

The homogenized global radiation on horizontal surface ($\bar{H}$) is used to compute the total radiation tilt factor $\bar{R}$ using the following correlation:

$$\bar{R} = \left(1 - \frac{\bar{H}_d}{\bar{H}}\right)\bar{R}_B + \frac{\bar{H}_d}{\bar{H}}\left(\frac{1+\cos\beta}{2}\right) + \rho_g\left(\frac{1-\cos\beta}{2}\right)$$

Where

- β is the tilt angle of the solar energy collection surface.

- ρ_g (is the ground Alpedo) = 0.2 (it is the measure of the ground surface reflection of the solar radiation and is taken as an average value).

- $\bar{R}_B$ (beam radiation tilt factor) $= \dfrac{\cos(L-\beta)\cos\delta\sin\tilde{h}_s + \frac{\pi}{180}\tilde{h}_s\sin(L-\beta)\sin\delta}{\cos L\cos\delta\sinh_s + \frac{\pi}{180}h_s\sin L\sin\delta}$

- L is the latitude which depends on the overlaid geographic location (grid).

- h_s (sunset hour angle) $= \arccos(-\tan L\tan\delta)$

- $\tilde{h}_s = \min(h_s, \arccos(-\tan(L-\beta)\tan\delta))$

- δ (declination angle) $= 23.45\sin\left[\frac{360(284+n)}{365}\right]$

• $\bar{H}_d(\text{diffuse}) = \bar{H}(1 - 1.13K_T)$

• $K_T(\text{is the clearance Index}) = \frac{\bar{H}}{H^o}$

• $H^o = \frac{24}{\pi} G_{sc} \left[1 + 0.033 \cos \frac{360 * dn}{365}\right] \left[\cos L \cos\delta \sinh_s + \left\{\frac{2\pi h_s}{360}\right\} \sin L \sin \delta\right]$

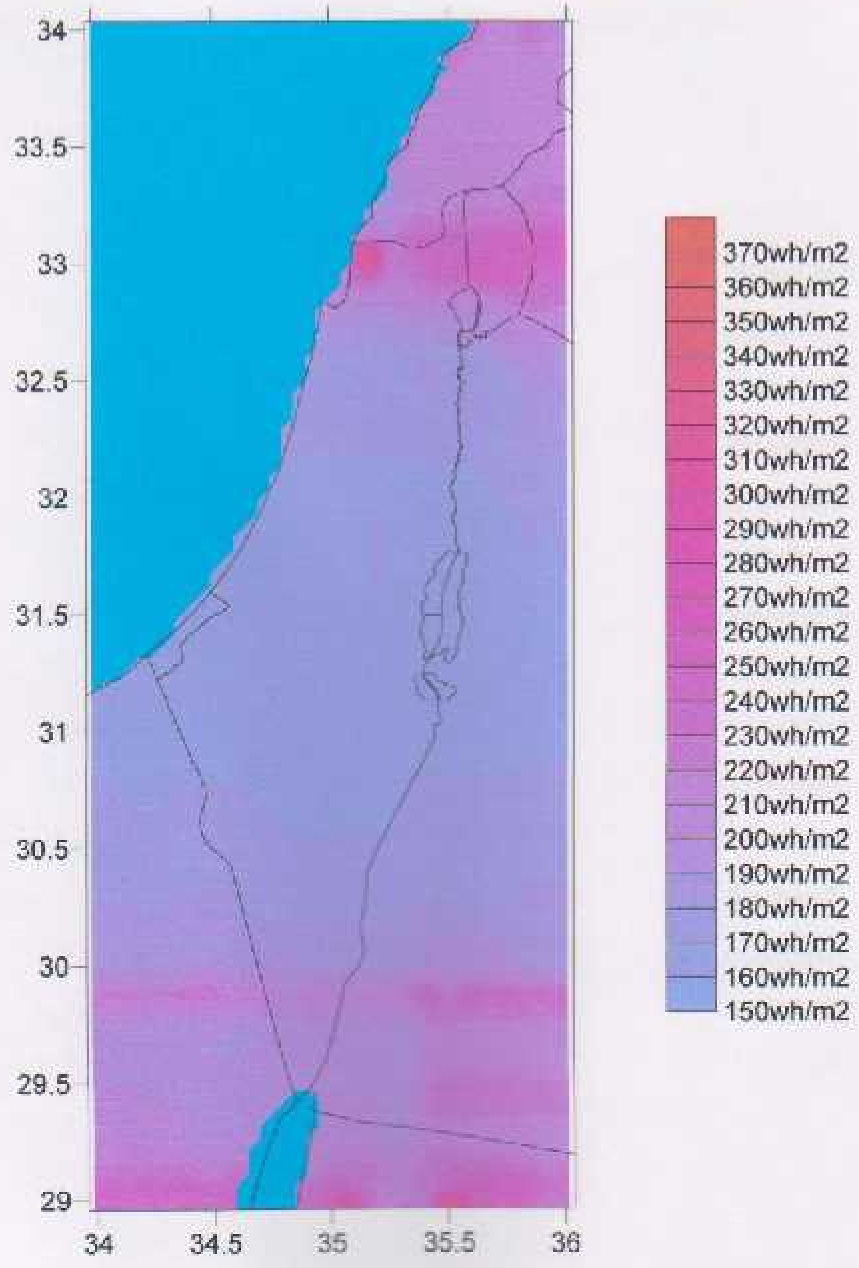
• $G_{sc}(\text{solar constant}) = 1.367\ KW/m^2$ taken as the mean value of the extraterrestrial radiation.

• dn is the day of the year (January $1^{st} = 1$)

The computed solar insulation homogenized over the domain is shown in the following figures (Fig. 4.1 – Fig 4.6). It could be pointed out here that the scattering of the available ground stations over the domain and the interpolated values together with the unavailability of the Palestinian Meteorological Data brought some shortcomings especially for some geographic areas shown in the maps figures (Fig. 4.1 – Fig 4.6).

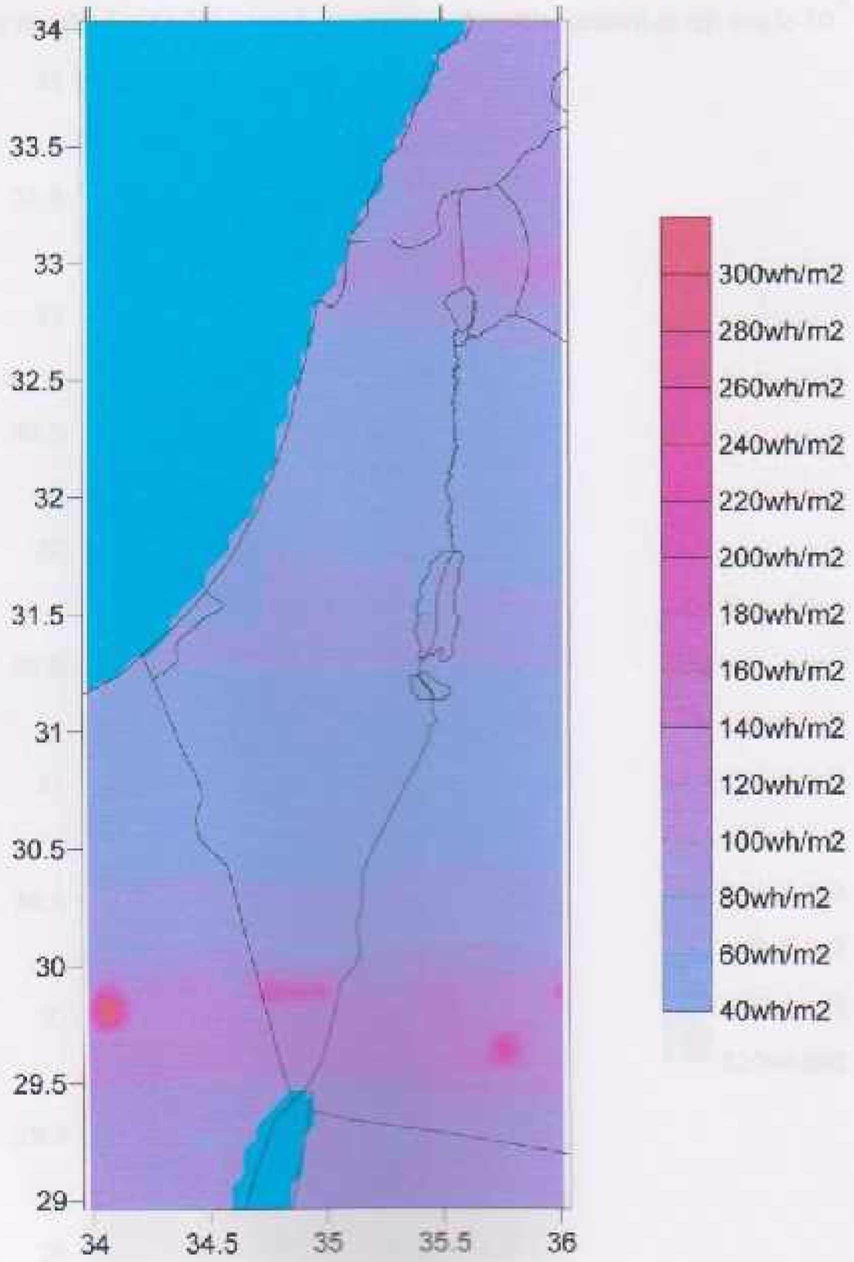
This problem could be resolved by supporting the available homogenized data with more records in other different geographical locations and validating the data.
It could be said that tilting the solar collectors by 45o-50o represents the optimal collection of solar radiation. The maps shows potential solar radiation collection places.

The resulted map for solar insolation at summer season at tilt angle 20°



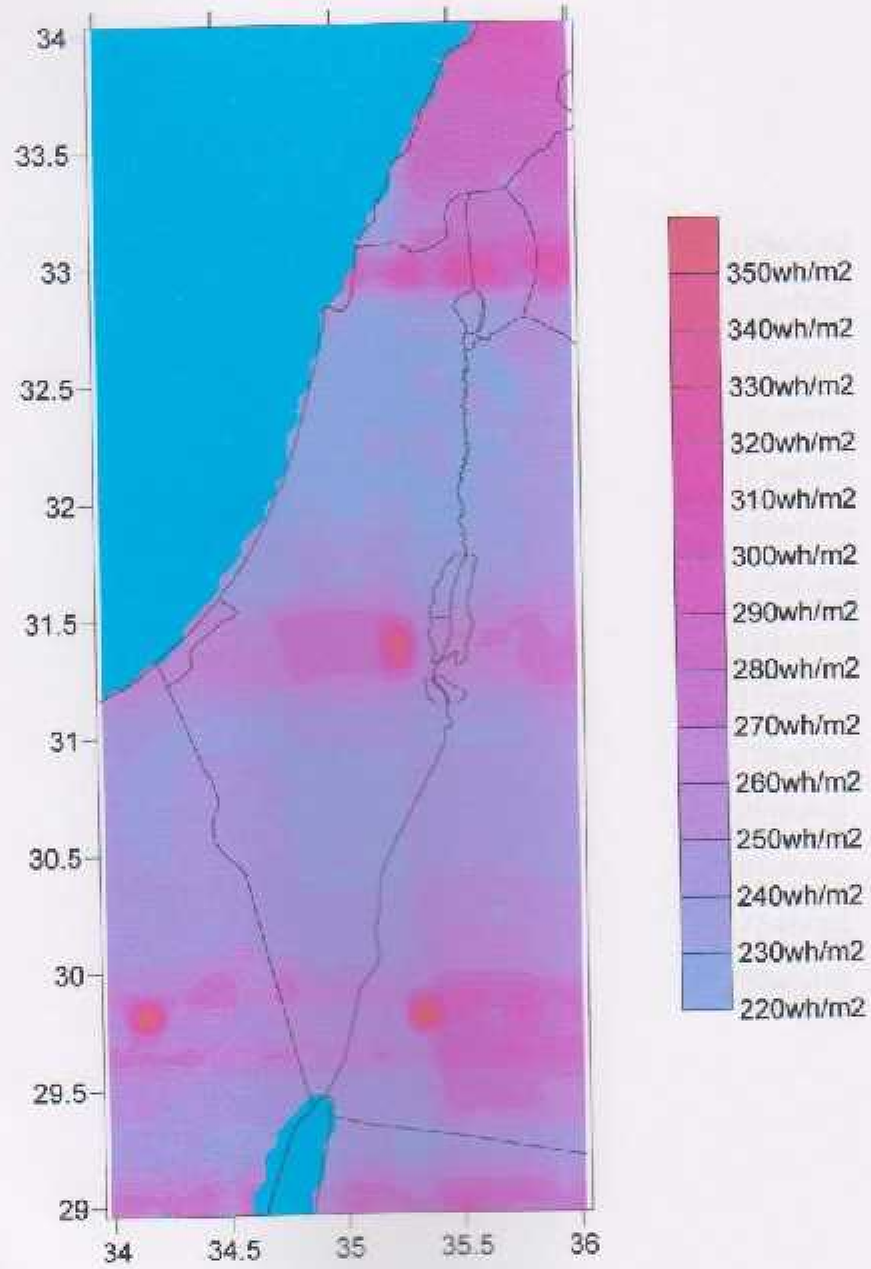
Fig(4.1) solar insolation map (summer, tilt 20°)

The resulted map for solar insolation at summer season at tilt angle 40°



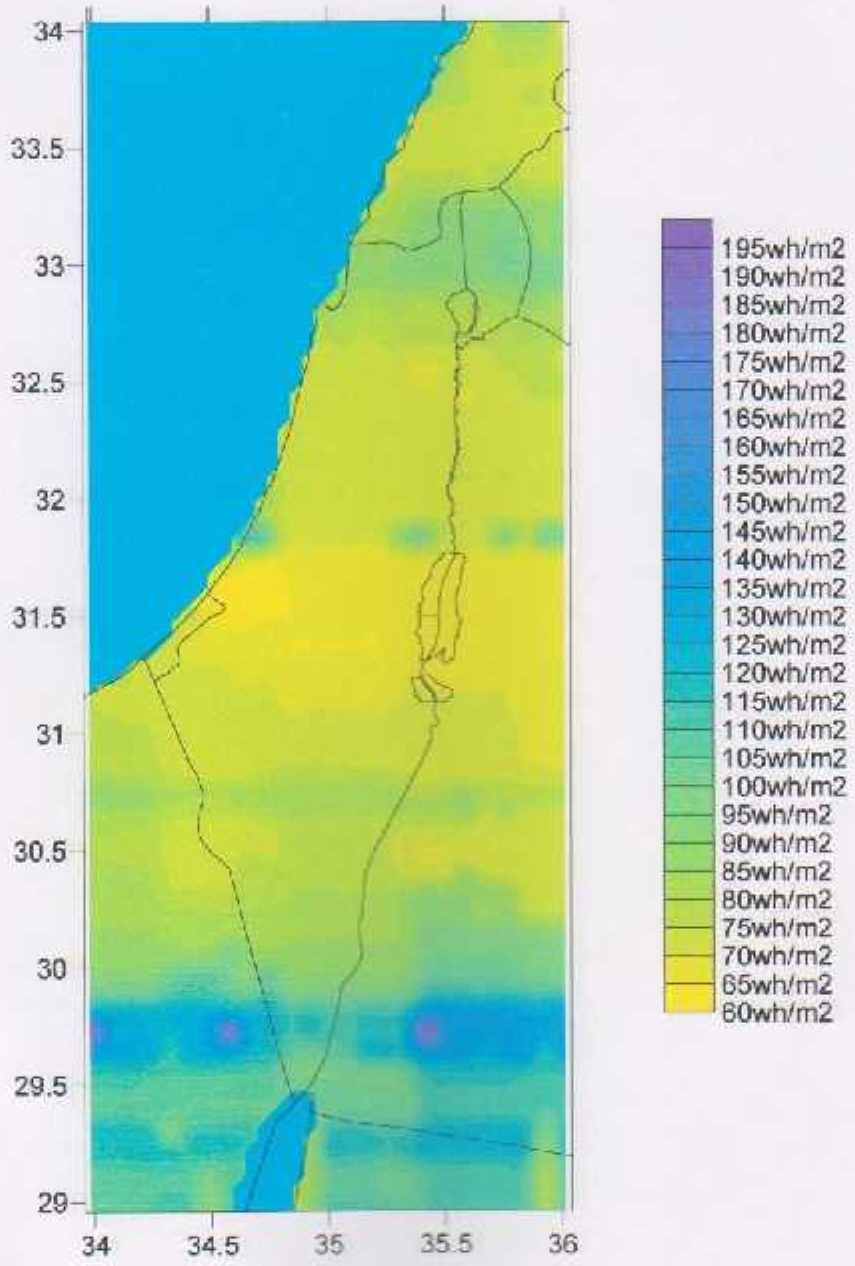
Fig(4.2) solar insolation map (summer, tilt 40°)

The resulted map for solar insolation at summer season at tilt angle 50°



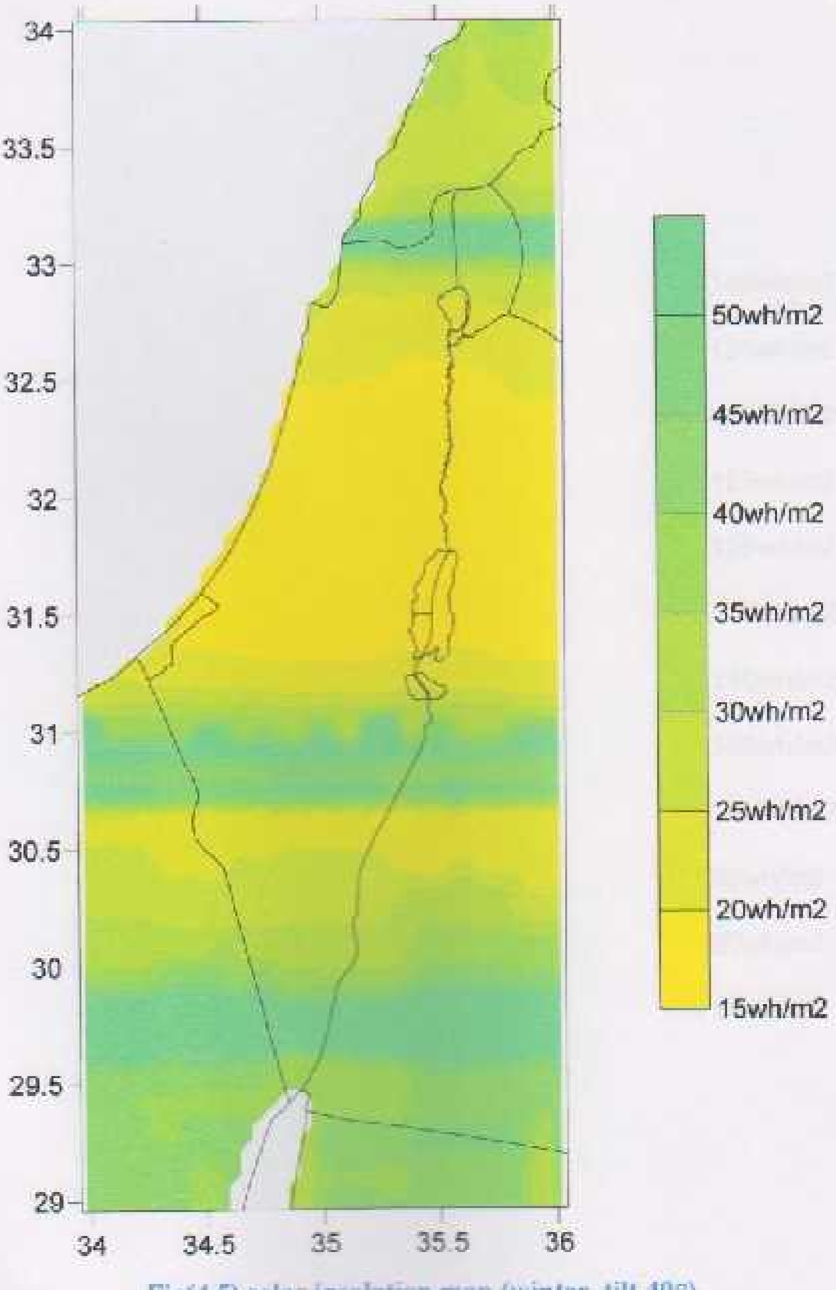
Fig(4.3) solar insolation map (summer, tilt 50°)

The resulted map for solar insolation at winter season at tilt angle 20°



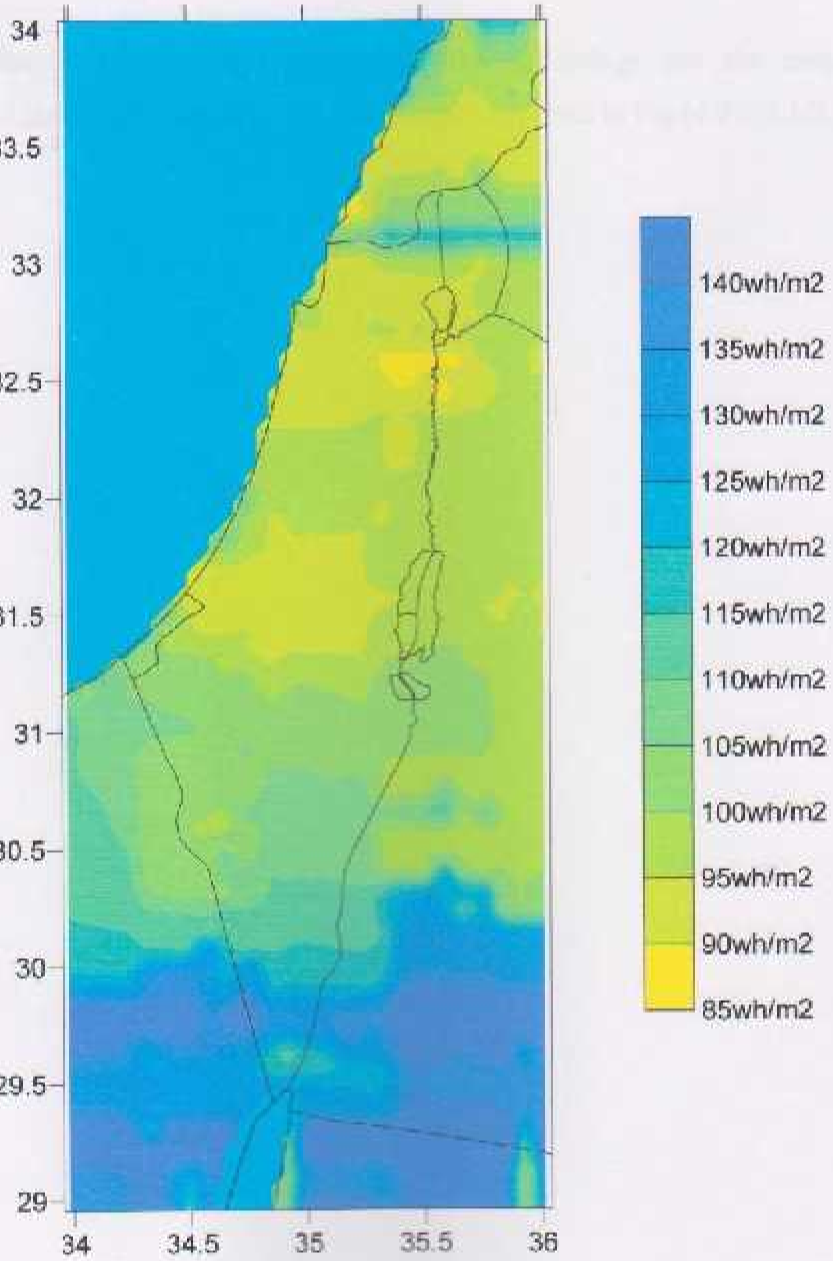
Fig(4.4) solar insolation map (winter, tilt 20°)

The resulted map for solar insolation at winter season at tilt angle 40°



Fig(4.5) solar insolation map (winter, tilt 40°)

The resulted map for solar insolation at winter season at tilt angle 50°

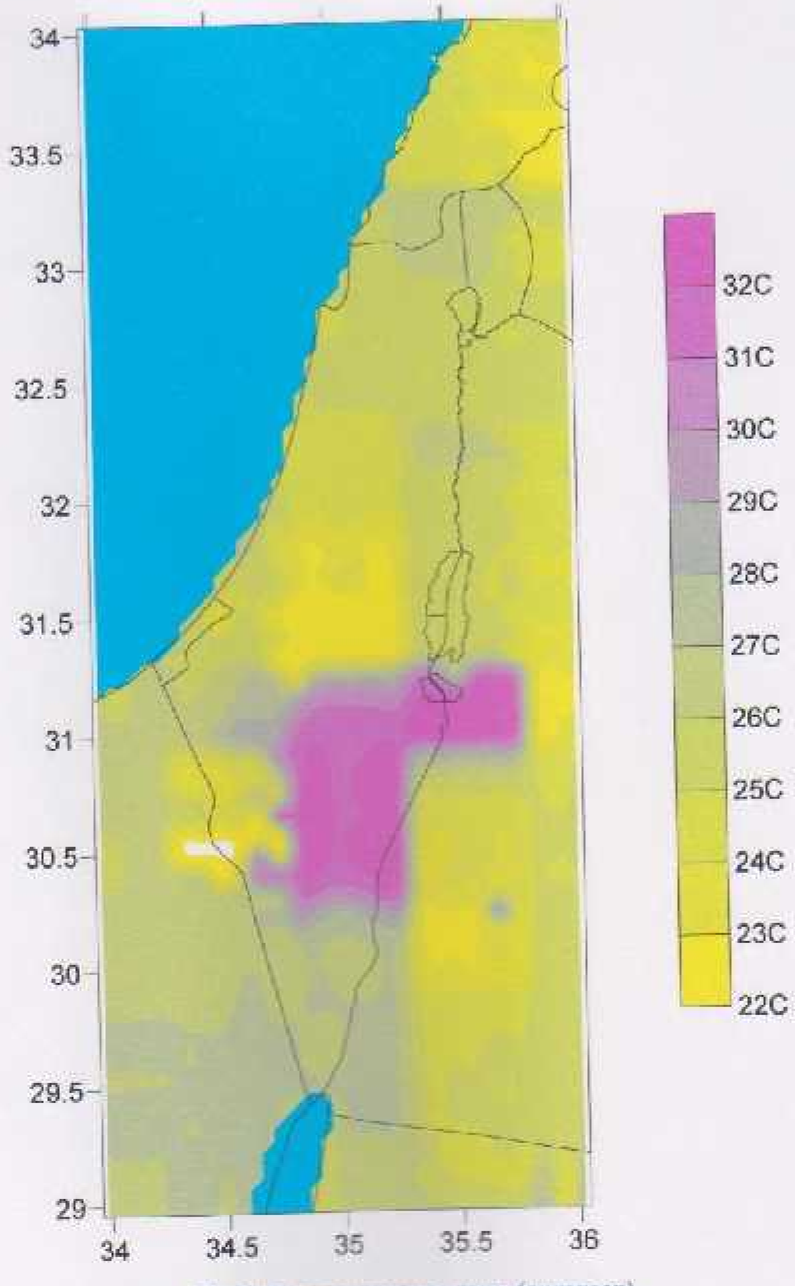


Fig(4.6) solar insolation map (winter, tilt 50°)

4.1.2 Temperature Maps on Different Seasons

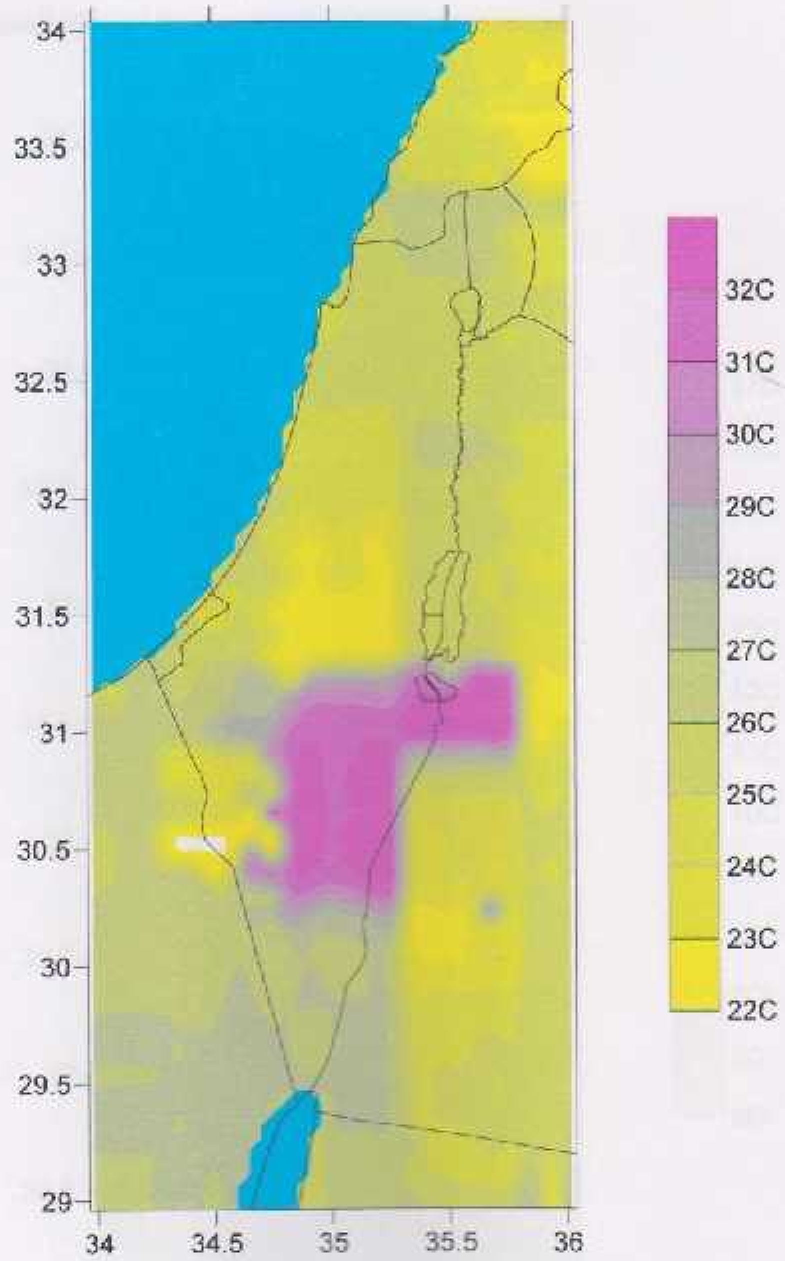
Similar to the seasonal irradiation, the followings are the maps for the homogenized air temperature over the said domain depicted in Fig (4.7 – 4.10).

The resulted map for temperature at summer season



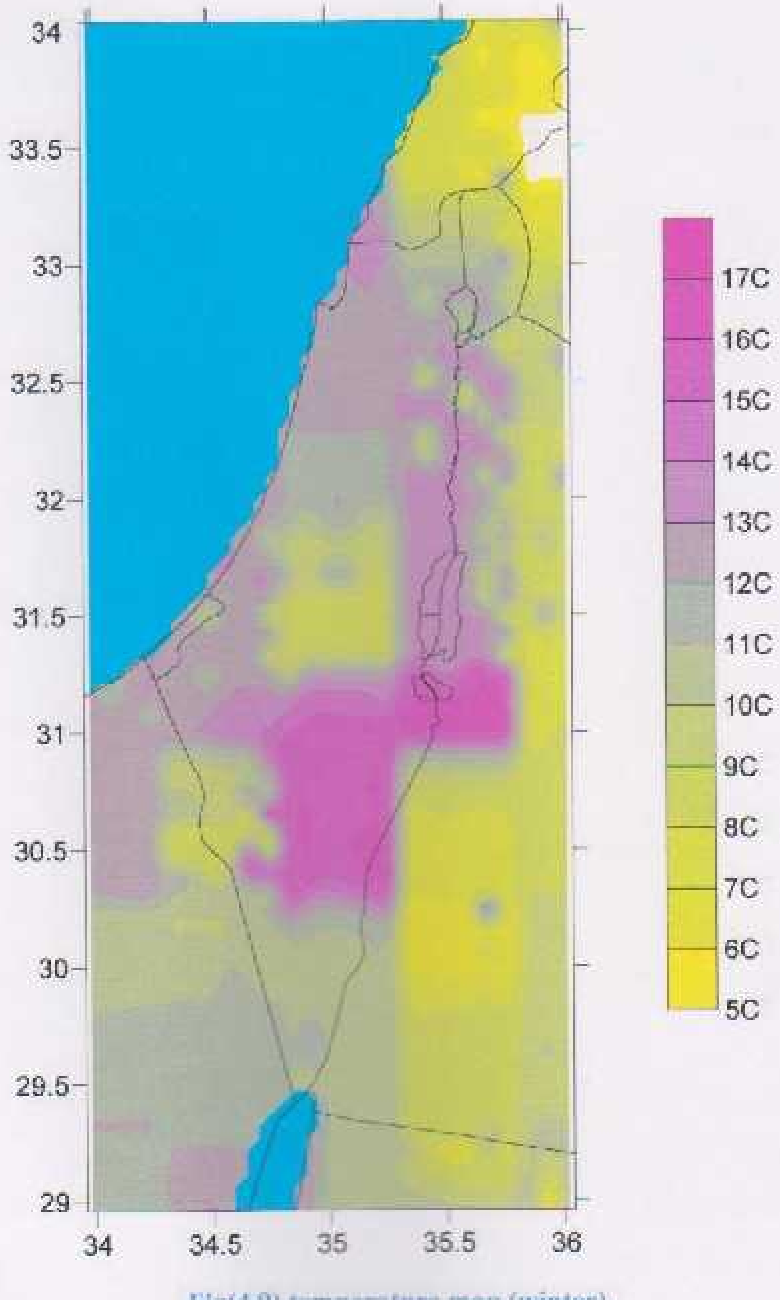
Fig(4.7) temperature map (summer)

The resulted map for temperature at spring season



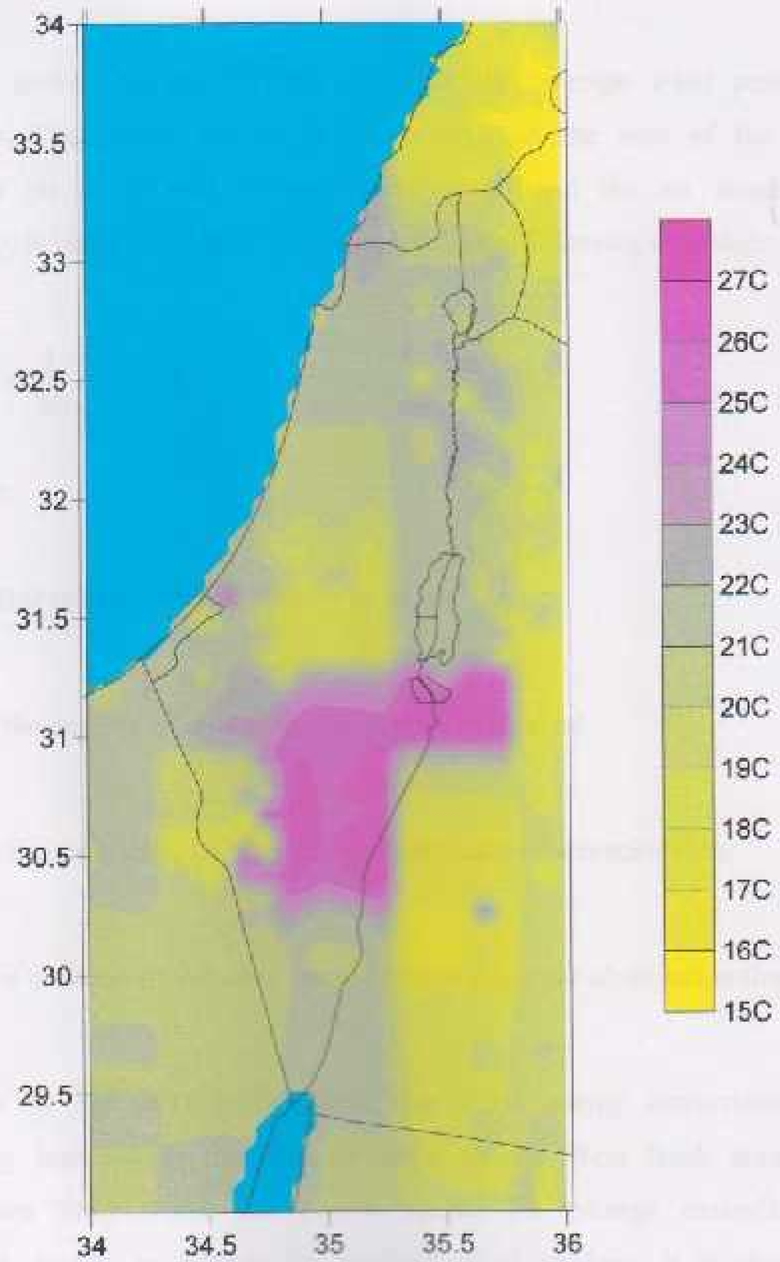
Fig(4.8) temperature map (spring)

The resulted map for temperature at winter season



Fig(4.9) temperature map (winter)

The resulted map for temperature at autumn season



Fig(4.10) temperature map (autumn)

4.2 Wind Energy Maps

4.2.1 Wind Power Density Maps

Wind power density (WPD) expresses the average wind power over one square meter. The power density is proportional to the sum of the cube of the instantaneous (or short-term average) wind speed and the air density, the wind power density, in units of (W/m2) is computed by the following equation:

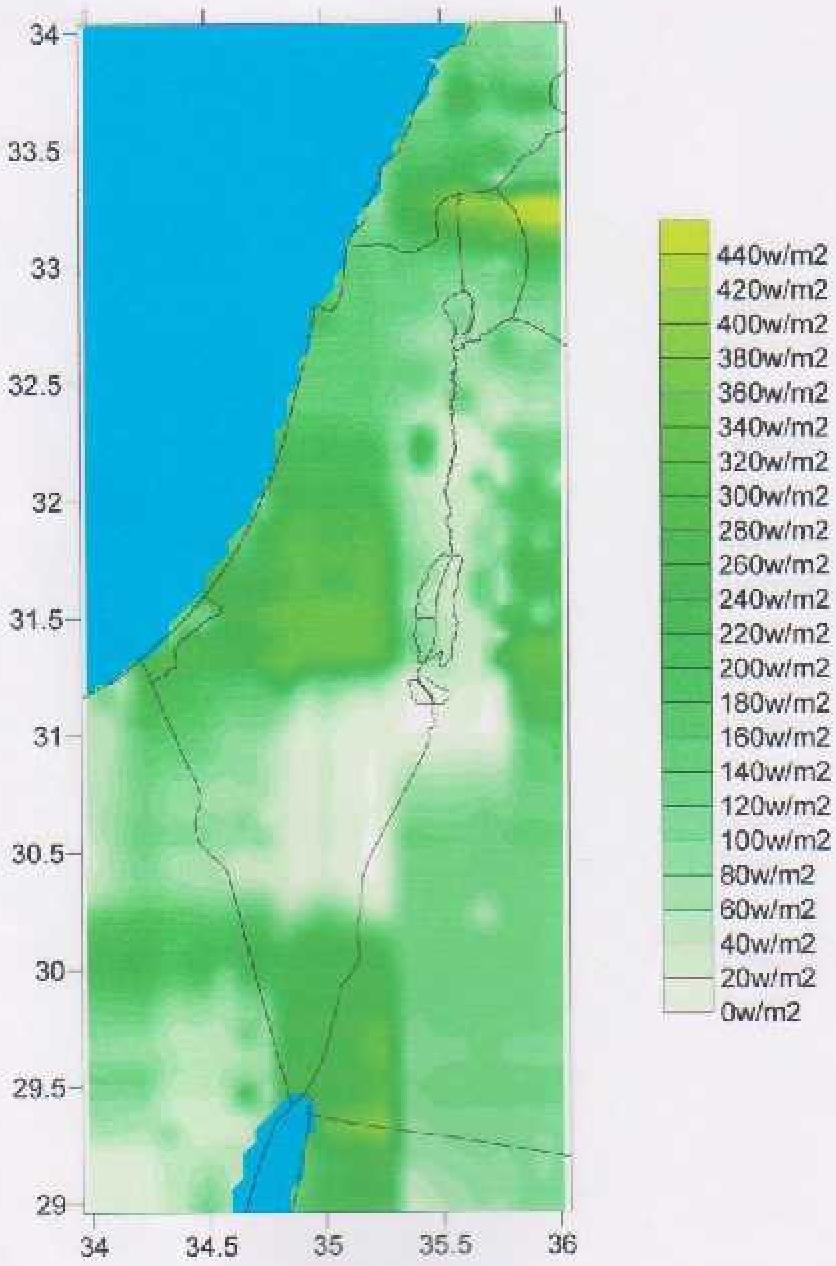
$$WPD = \frac{1}{2n}\sum_{i=1}^{n} \rho . V^3{}_i$$

Where

- WPD is the wind power density in W/m^2
- n is the number of records in the averaging interval.
- ρ is the air density (in Kg/m^3) at a particular observation time.
- $V^3{}_i$ is the cube of the wind speed (m/s) at the some observation time.

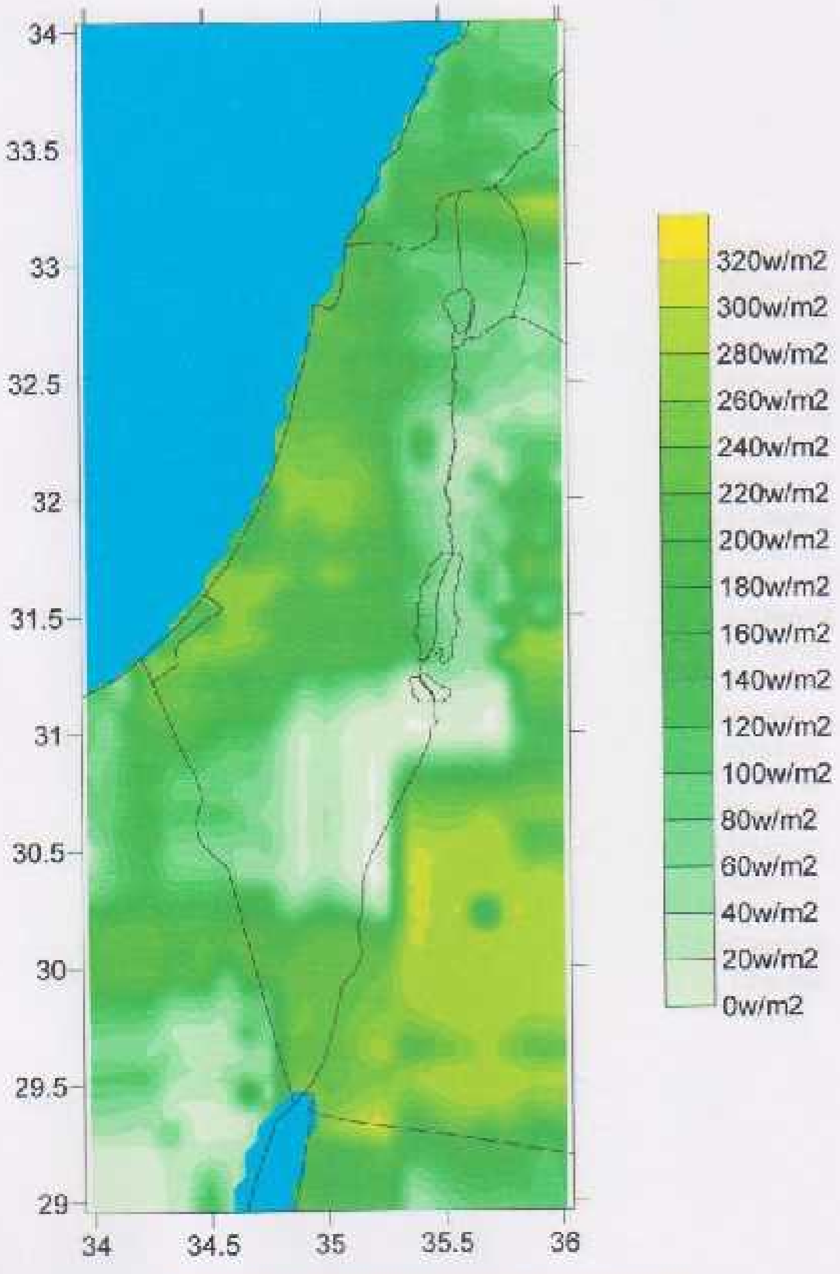
Maps shown in Fig (4.11-4.14) shows that wind energy conversion system can be potentially installed in the western slope of the West Bank area and on the shore in Gaza Strip where the power density on average exceeds 250 W/m2. Such average density is suitable for medium wind turbines. It is clearly seen that wind power density approaches zero in the Jordan rift valley.

The resulted map for wind power density at summer season



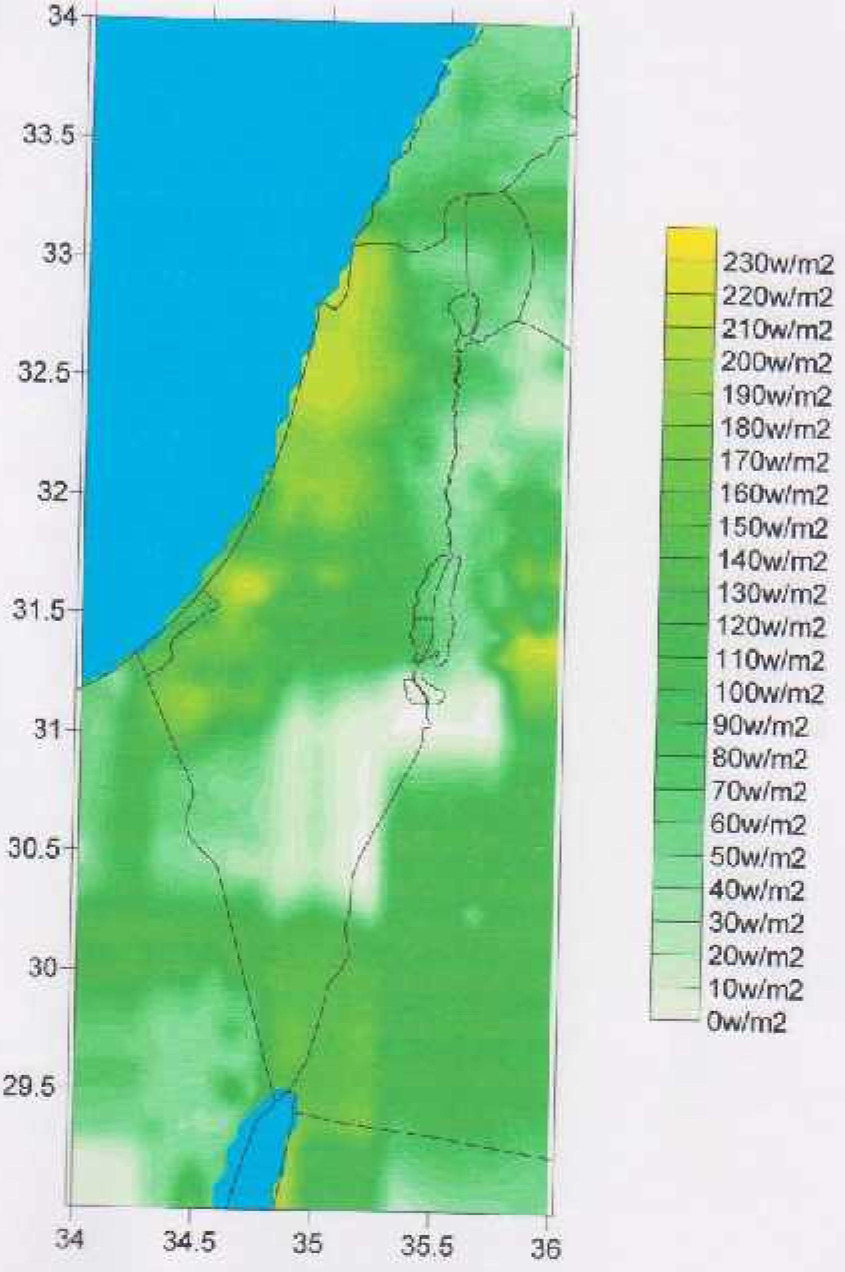
Fig(4.11) wind power density map (summer)

The resulted map for wind power density at spring season



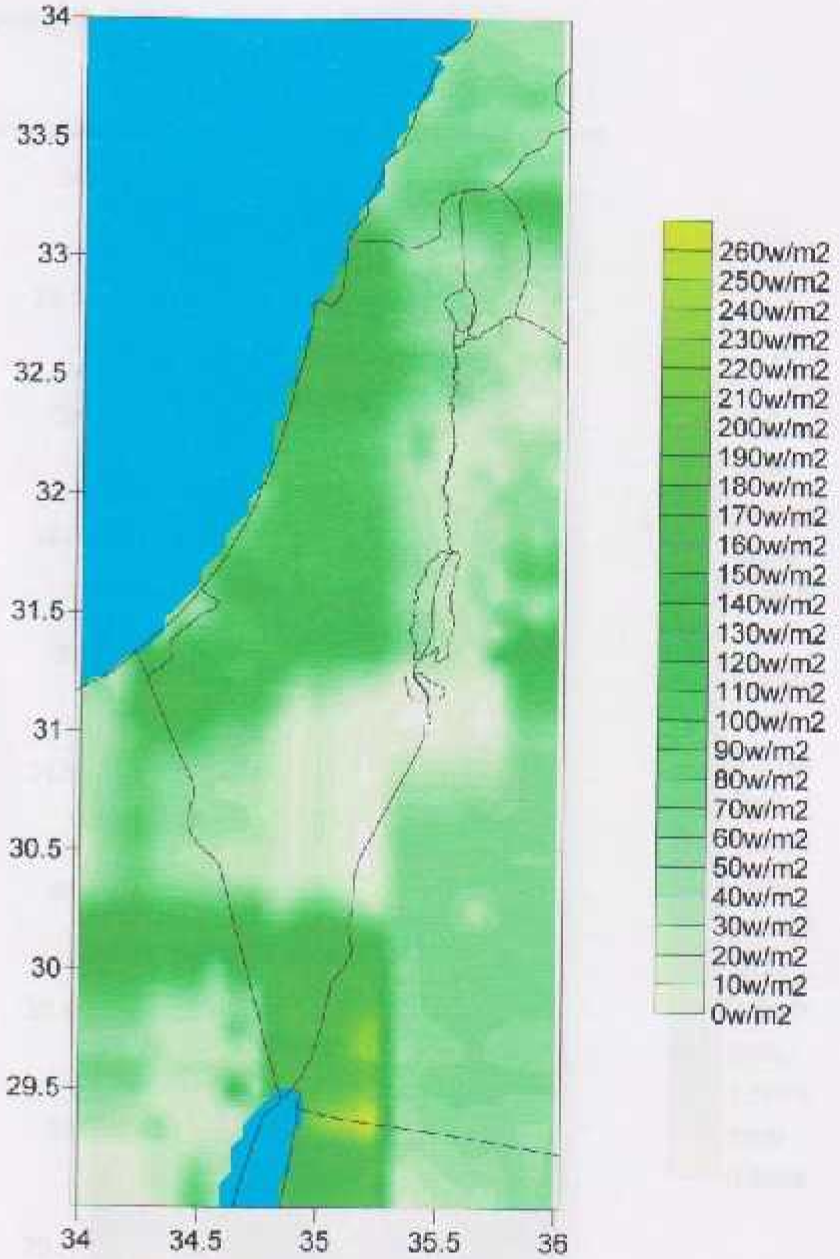
Fig(4.12) wind power density map (spring)

the resulted map for wind power density at winter season



Fig(4.13) wind power density map (winter)

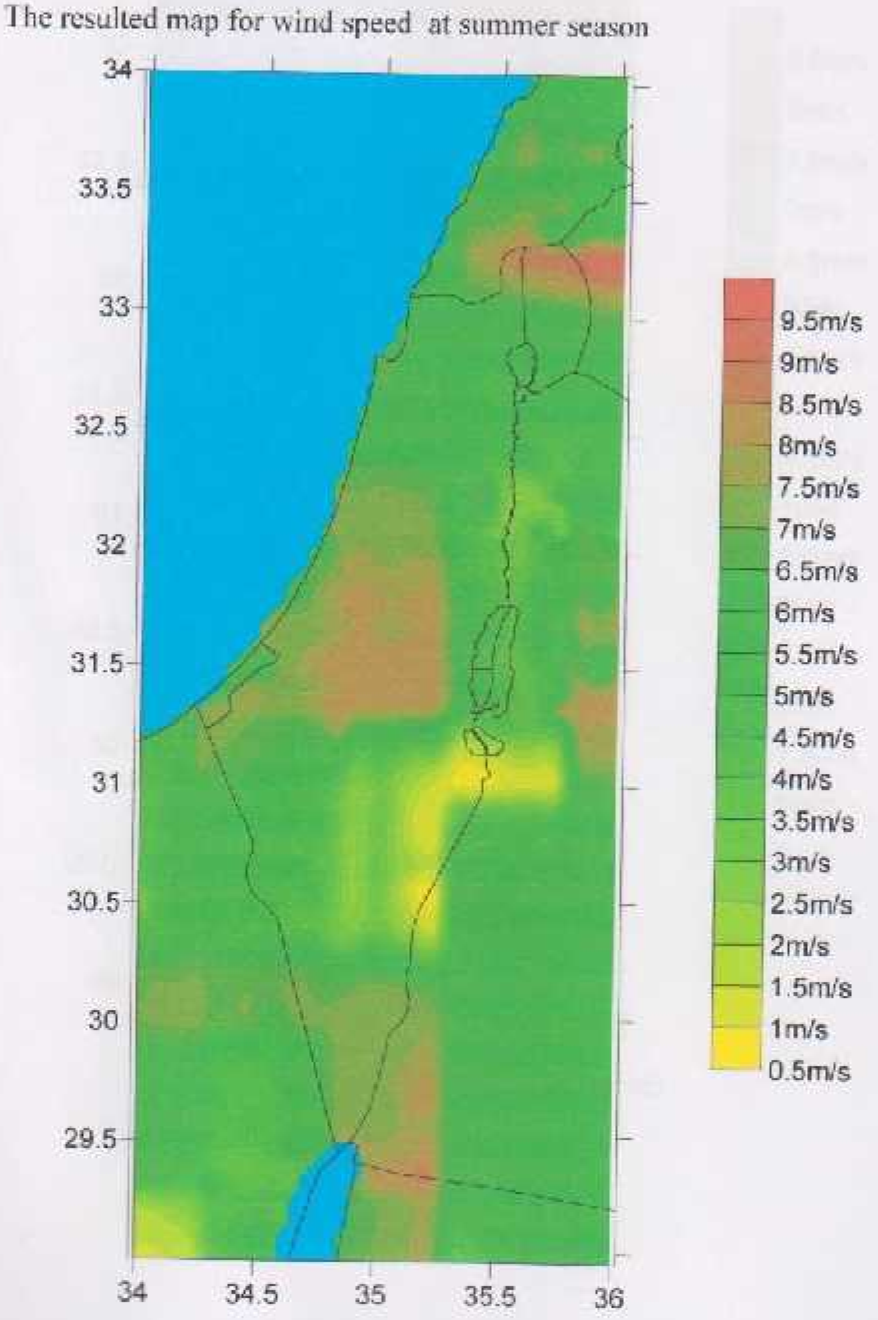
The resulted map for wind power density at autumn season



Fig(4.14) wind power density map (autumn)

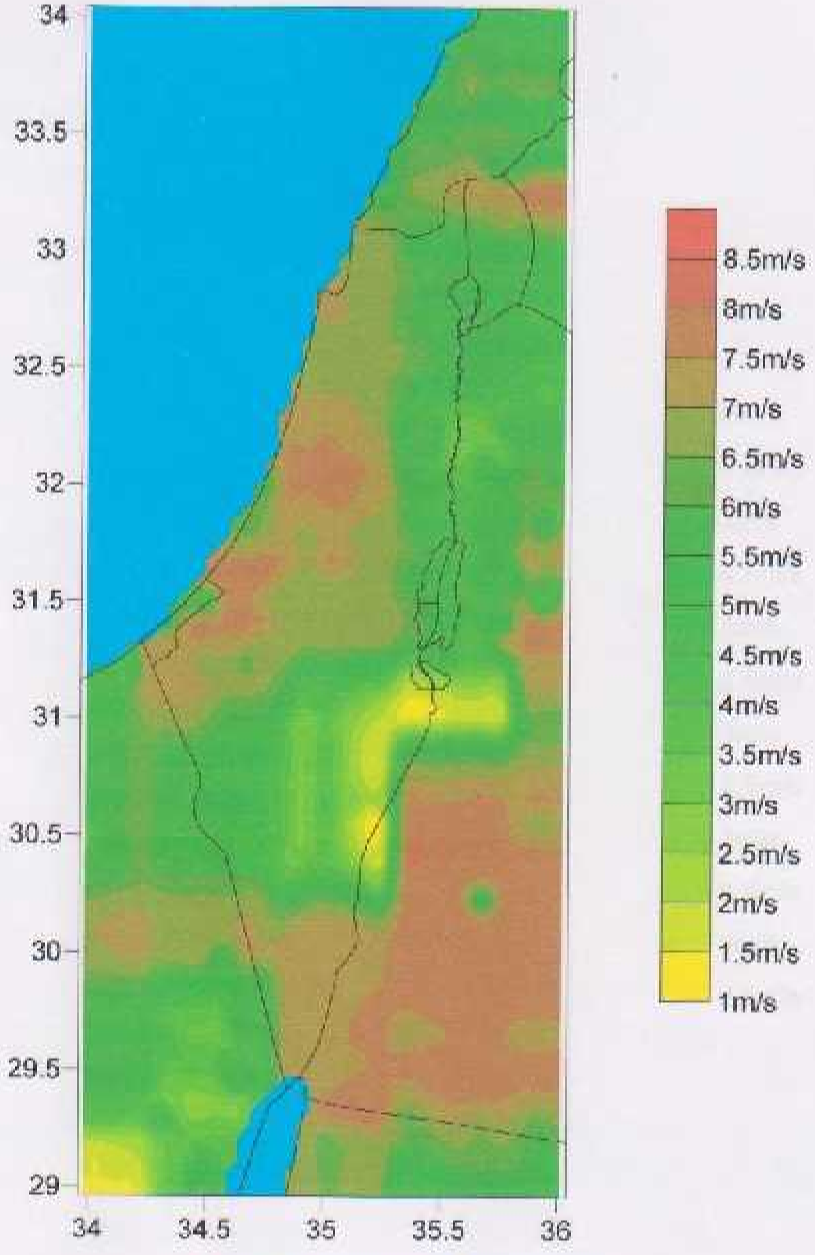
4.2.2 Wind Speed Maps

Similar to wind power density, wind speed are plotted over the domain in the following figures, Fig (4.15-4.18).



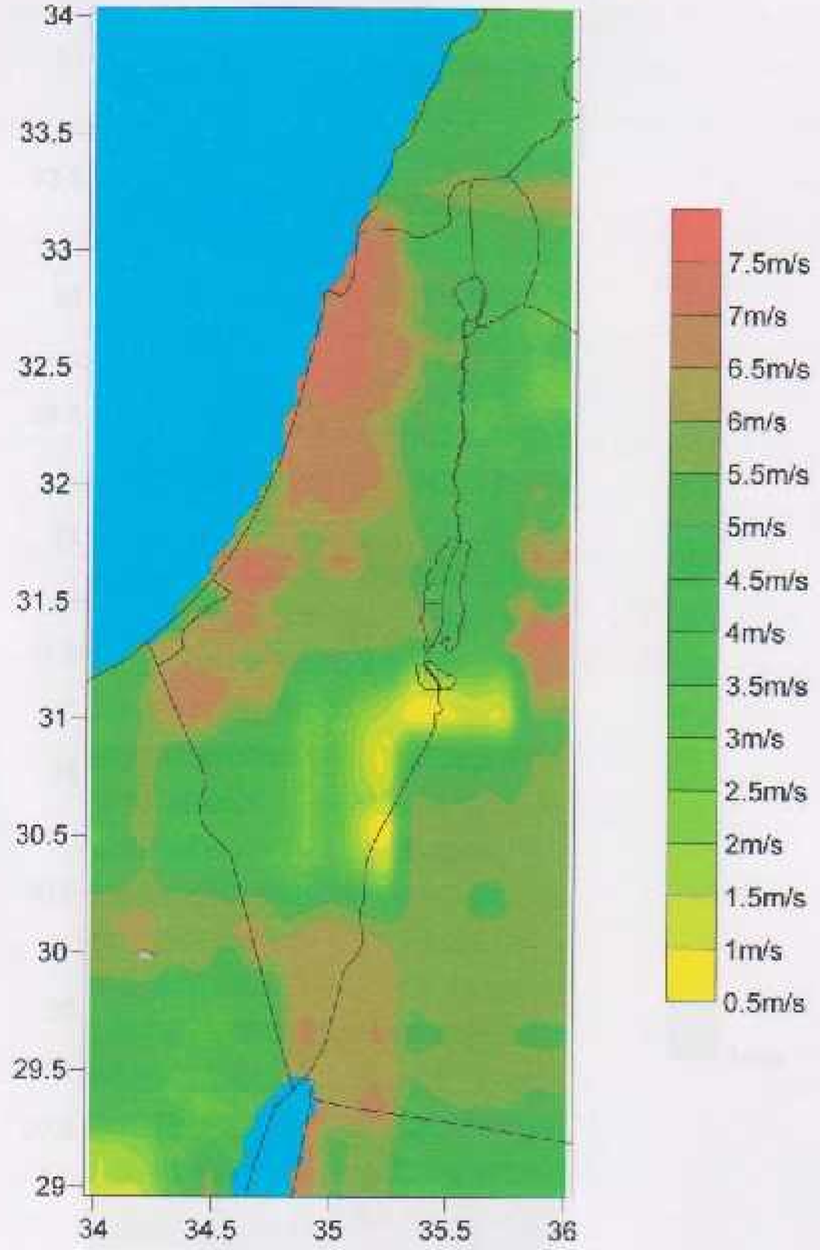
Fig(4.15) wind speed map (summer)

The resulted map for wind speed at spring season



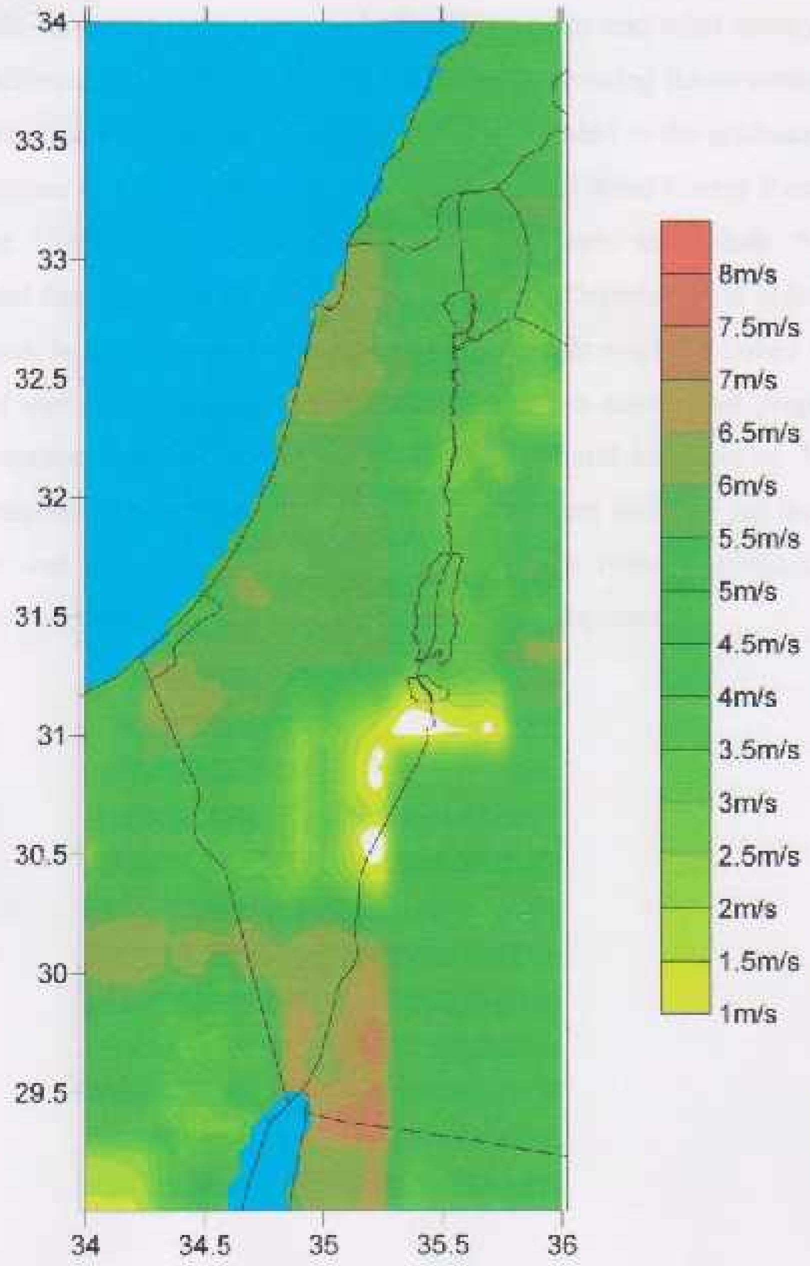
Fig(4.16) wind speed map (spring)

The resulted map for wind speed at winter season



Fig(4.17) wind speed map (winter)

The resulted map for wind speed at autumn season



Fig(4.18) wind speed map (autumn)

Conclusions:

The Solar and Wind Energy Resources Maps for Palestine are very important and effective tools for assessing the potential of utilizing solar and wind energy conversion systems in different places. They are very essential for planning future strategies on best effective utilization of available resources. The effort exerted in the graduation project is the first milestone in a development of a reliable Solar and Wind Energy Resources Maps for Palestine (SWERMP). Extra effort should be made to include the available meteorological data from the Palestinian Meteorological Department in order to increase the preciseness. In addition, data with maps could be made available online using one of the graphical user interface programs that enable users to assess their proposed energy conversion system installed in any location. This should be done by lobbying the national institution showing how important such resources and tool for the sustainable development and that data should be provided for any research effort that enhance national knowledge on issues of relevant to national development.

References

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