PRELIMINARY RESULTS OF SITE SELECTION STUDY FOR CLOUD SEEDING IN ORDER FOR PRECIPITATION ENHANCEMENT IN I. R. OF IRAN

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Abstract. Weather modification activities in I. R. of Iran includes site selection study as well as numerical cloud seeding modeling and field experiments for fog dispersion and rain enhancement. In this paper the primary results of site selection study for cloud seeding in order for precipitation enhancement in I. R. of Iran has been presented. The procedure is according to Precipitation Enhancement Project (PEP) Report No. 3 of the World Meteorological Organization (WMO). The results procedure has shown that the cloud seeding feasibility is highest at the northwest, north and northeast of Iran and it decreases from north to center, south and east of center. The results are very important for design of operational projects over Iran to classify capability for cloud seeding.

1. INTRODUCTION

Weather modification activities to enhance water supplies have been conducted for a wide variety of users including water resource managers, hydro-electric power companies, and agriculture. The ability to influence and modify cloud microstructure in certain simple cloud systems such as fog, thin layer clouds, simple orographic clouds, and small cumulus clouds, has been demonstrated and verified in laboratory, modeling, and observational studies (AMS, 1992). Although past experiments suggest that precipitation from single-cell and multi-cell convective clouds may be increased, decreased, and/or redistributed, the response variability is not fully understood. It appears to be linked to variations in targeting cloud selection criteria, and assessment methods.

The complexity of atmospheric processes and specifically cloud and precipitation development has prevented significant progress in developing a cloud seeding technology that can be tested and verified by the scientific community.

Water is one of the most basic commodities on earth sustaining human life. In many regions of the world, however, traditional sources and supplies of ground water, rivers and reservoirs are either inadequate or under threat from ever increasing demands on water from changes in land use and growing population.

As well as many countries around the world, the shortage of water supplies is one of the most important problem in I. R. of Iran (Fig.1) which has a dry and semi-dry climate (Fig. 2), especially as recently as 5 years ago, where severe drought occurred in most regions of Iran.

In addressing the challenge of balancing increasing human requirements for adequate water supplies and improved health and sanitation with food production, transportation, energy and environmental needs, most countries will require more effective governance, improved capacity and adequate financing.

The Dialogue on Water and Climate and the Associated Programme on Floods have been building bridges between water managers, climatologists, hydrologists, and disaster management organizations, as well as raising awareness amongst water policy makers, water managers and society about the need for better adaptation to climate change and increasing meteorological hazards.

Johannesburg Summit 2002 – the World Summit on Sustainable Development – brought together tens of thousands of participants, including heads of State and Government, national delegates and leaders from non-governmental organizations (NGOs), businesses and other major groups to focus the world's attention and direct action toward meeting difficult challenges, including improving people's lives and conserving our natural resources in a world that is growing in population, with ever-increasing demands for food, water, shelter, sanitation, energy, health services and economic security.

To help alleviate some of the stresses, the cloud seeding for precipitation enhancement has been used as a tool to help to mitigate dwindling water resources in this country.

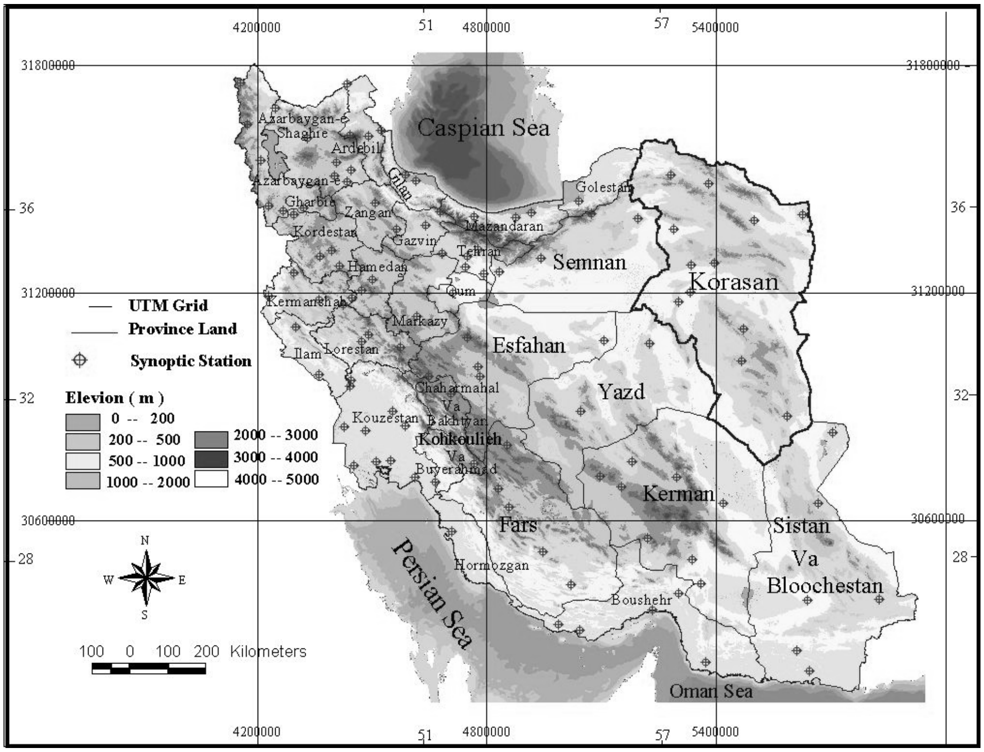

Figure 1. Map of I. R. of Iran and its Neighbors.

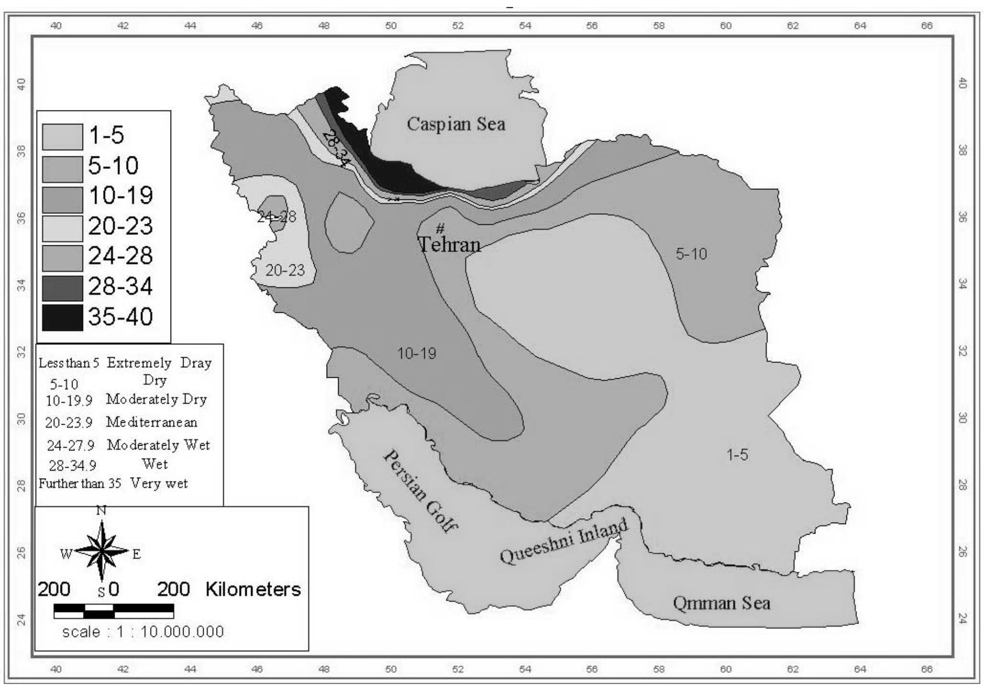

Figure 2. Climatic classification of Iran using modified Domartan method.

As it has been reported, the first cloud seeding project in Iran was conducted by a Canadian weather engineering company from 1974 to 1978 over Jajroud basin. The aim of that project was increasing storing water behind Karaj and Latian dams to supply drinking water for Tehran city. According to their report, efficiency of about 15% was achieved (Ministry of Energy, 1975). Then the cloud seeding project was carried out in the response of Yazd regional governor in Shirkooh mountains (as target area) from 1989 to 1995 (IRIMO, 1995). Later, some experiments in cloud seeding have been conducted at National Center for Cloud Seeding in Iran by Russian experts from 1995 until now. On the other hand, fog dispersion seeding using homogenous substance, Liquid Carbon dioxide (LC) has been carried out successfully in Firoozkooh mountains around Tehran city in I. R. of Iran Meteorological Organization (IRIMO) (BodaghJamali et al., 2002). Also, improved numerical modeling of Roll-up Expansion of Twin Horizontal Ice crystal Thermal (RETHIT) and Falling-growth Induced Lateral Air Spreading (FILAS) in LC seeding based on field experiment over northern Kyushu Island of Japan was improved in 2003 (BodaghJamali et al., 2003). In recent years, due to the necessity of Site Selection Phase (SSP) study for cloud seeding experiment, the cloud seeding feasibility study project has been conducted in IRIMO (Javanmard et al., 2003). In this paper the primary results of the cloud seeding feasibility study in Iran will be presented, which has been carried out at Climatological Research Institute (CRI) and Atmospheric Science and Meteorological Research Center (ASMERC).

2. WMO PROCEDURE FOR SSP

The seventh WMO Congress in 1975 approved a WMO Weather Modification Programme. The most important element of this programme was the Precipitation Enhancement Project (PEP).

Considering that the results of most rain-making projects up to that time had been inconclusive because of the lack of sound scientific planning, operation and evaluation, the Congress agreed that scientifically convincing answers concerning the feasibility of precipitation enhancement could best be advanced through an internationally planned, executed and evaluated experiment in precipitation simulation. Besides, the detailed study of meteorological, climatological, hydrological and environmental considerations was a prerequisite for selection of an appropriate site (WMO PEP, No. 3, 1976). According to WMO PEP No. 3 report in 1976, the procedure for the site selection was introduced in 3 stages as following; Stage 1: questionnaires and preselection, stage 2: visits to sites and climatological studies etc., and stage 3: detailed microphysical investigations and other studies. In the first stage, PEP site-selection criteria should be met. Table 1 is an objective method of allotting marks to site under various criteria. It includes physical characteristics of site, such as size, and degree of homogeneity, characteristics of precipitation, including annual amount, regime, prop. liquid to solid at ground, length of rainy season, availability of meteorological data, including density of rain gauge network, length of record, other data (radar, rawinsound), and facilities has been gathered in the site.

Based on the questionnaires of WMO as mentioned above (Table 1), this study was carried out over Iran.

3. RESULTS OF WMO SSP OVER IRAN

The I. R. of Iran lies in the western part of the Iranian plateau in the north and eastern hemispheres and the south-west of Asia, and is located approximately between 48°E and 26°E and 26°N and 36°N. Its neighbors consist of Azerbaijan, Turkmenistan and Armenia in the north, which are around the Caspian Sea, Afghanistan and Pakistan in the east and Turkey and Iraq in the west, as shown in Figure 1.

I.R. of Iran enjoys a diverse climatic condition. The country is mainly arid or semi-arid. Except for the northern coastal areas, the climate is extremely continental. In summer, hot and dry weather prevails generally, and in winter, very cold weather is usual, in particular inland areas as shown in Fig. 2. The rainy period in most of the country is from November to May. The average annual rainfall is about 230 ~ 250 mm.

There are 200 synoptic meteorological stations (Fig. 3). The data of 200 stations from 1951 to 2000 has been used in this study. Spatial distribution of precipitation (Fig. 4), snow-coefficient, and temperature (Figs. 5 & 6) using the data from 200 stations in period of 50 years in Iran shows that the average of annual precipitation is about 230 ~ 250 mm. Climatological data for cloud seeding in Iran, for example, in January is shown in Figs. 4-8. Average precipitation in January is high in the north and south west; it is about 150 mm (Fig. 4). Average minimum temperature in January is lowest in north west and north east, it is about –10 °C and –3 °C respectively (Fig. 5). Average maximum temperature in January is highest in south, and center of Iran, it is about 15 °C (Fig. 6). Average relative humidity in January is highest in northeast, north, northwest and southwest, it is about 80% (Fig. 7). The annual average of cloudiness (3-6/8), in other words, the number of days per year with cloudiness between 3 and 6 octals over Iran during 1975-1995 has been shown in Fig. 8. It shows that the cloudiness is high in northwest, north and northeast part of Iran and it will decrease in center, north, and east part of Iran.

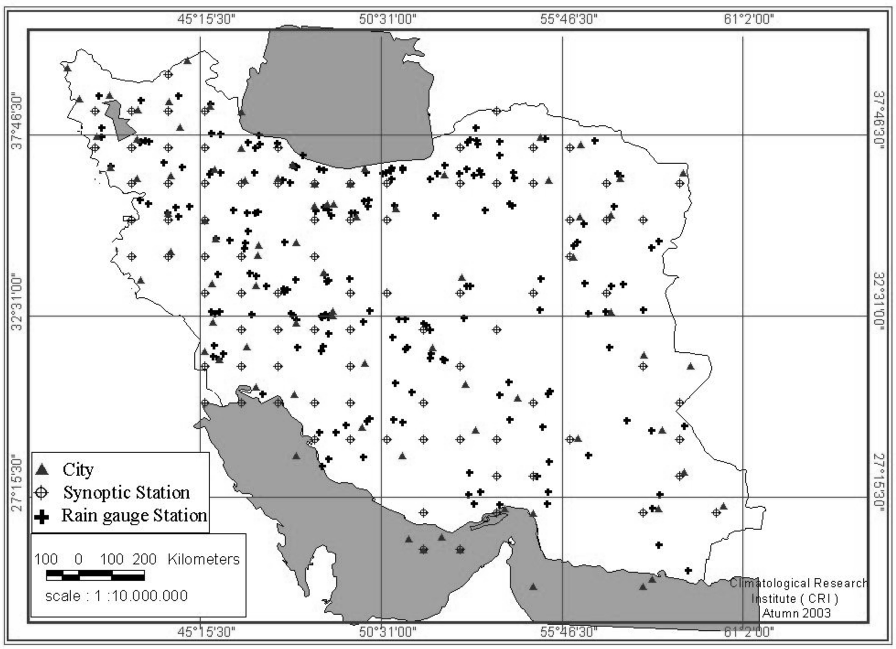

Figure 3. Meteorological station network of IRIMO in Iran.

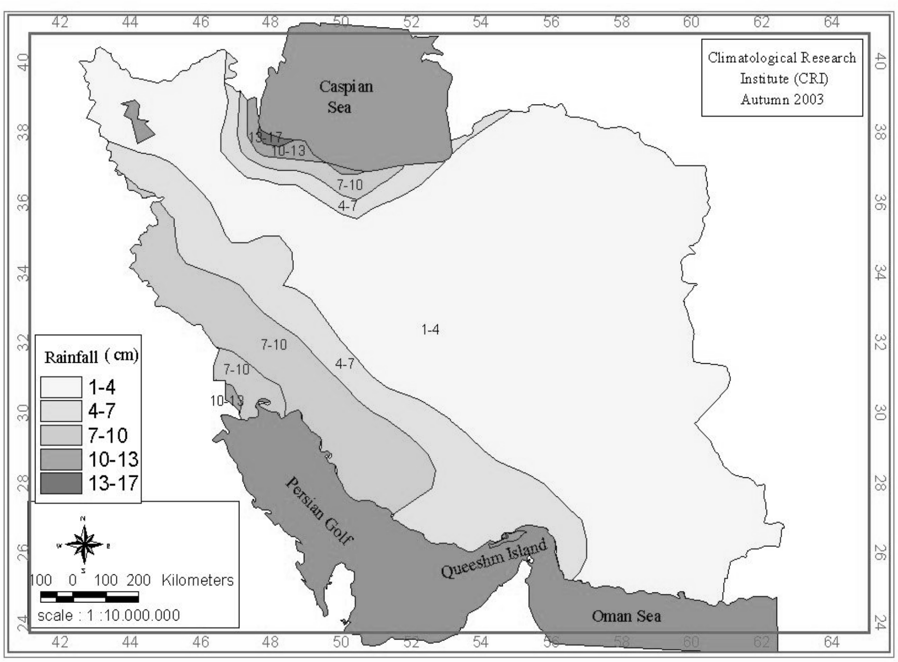

Figure 4. Contour of average precipitation on January during long term period (1951-2000.)

Table 1. PEP site selection criteria objective method of allotting marks to site under various criteria

Criterion	Score					
	0	**1**	**2**	**3**	**4**	**5**
1. Size of site (km^2 ×10^3)	<20	20-25	25-30	30-40	40-50	≥50
2. Degree of homogeneity f-flat, u-undulating, h-hilly, m-mountainous	f+u+h+m, f+u+m f+m f+h+m	M f+u+h u+m u+h+m	h+m, f+h m	u+h,	H,	f, u, f+u
3. Annual pptn. (cm)	≤25 ≥100	25-30 91-99	31-35 86-90	35-40 81-85	41-50 71-80	51-70
4. Pptn. Regime a-arog., b-conv., c-extra-trop. fronts d-trop. cyclone, e-monsoon, f-equat.	a (warm) b (warm)	D	a(cold)	b(cold) a+b e, f	C+b+a	c c+a
5. Portion of pptn. as liquid (%)	<60	60-70	70-80	80-85	85-90	>90
6. Length of rainy season (months)	>8	8-7	7-6	6-5	5-4	4-3
7. Density of gauge (per 1000 km^2)	<.1	0.1-0.5	0.5-2	2-4	4-6	>6
8. Length of record (years)	<10	10-15	15-20	20-30	30-40	>40
9. Other data: a-rawinsonde data, b-aircraft data, c-radar data		b, c	a<5	5<a<10 (a<5)+b, (a<5)+c	a>10 (5<a<10)+b, (5<a<10)+c	(a>10)+b (a>10)+c
10. Flight restrictions: a-none, b-minor, c-severe, d-ban Facilities: x-poor, y-average, z-modern	d, c+x	b+x, c+y	b+y, c+z	a+x, b+z	A+y	a+z
11. Communications: a-good road system, b-satisfactory roads, c-bad roads, d-postal service, e-telephones		C	B, c+d, c+e	c+d+e, b+d, b+e+a	a+d, a+e, b+d+e	a+d+e
12. Working conditions: a-satisfactory accommodation b-poor accommodation c-medical facilities d-cultural facilities e-adequate electric power		b	b+c, b+c, b+c	a+c, a+d, a+e b+c+d, b+c+e, b+d+e	a+c+d, a+d+e, a+c+e, b+c+d+e	a+c+d+e

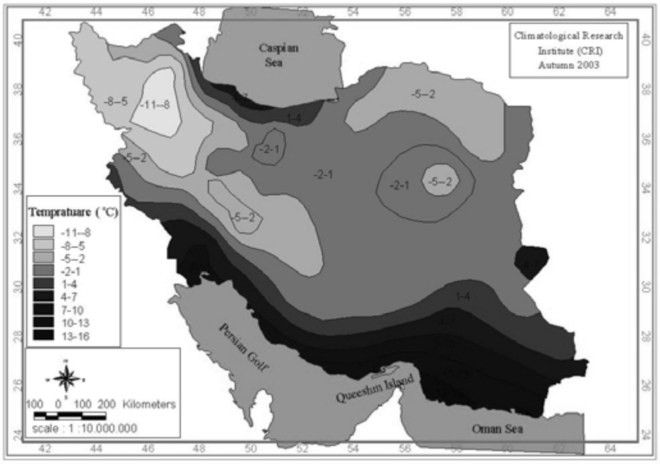

Figure 5. Spatial distribution of average minimum temperature on January during long-term period (1951-2000)

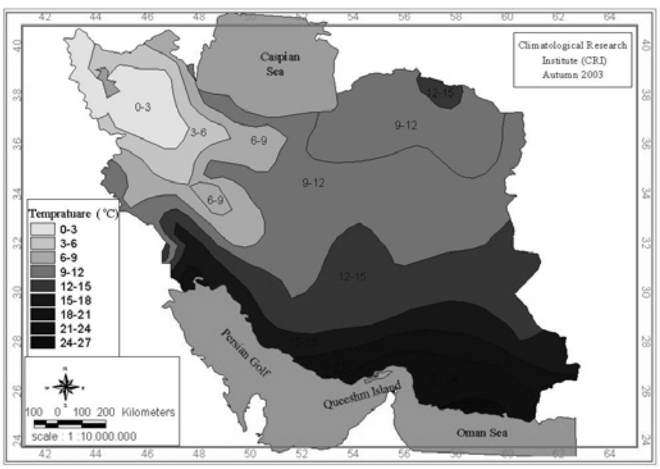

Figure 6. Spatial distribution of average maximum temperature on January during long term period (1951-2000)

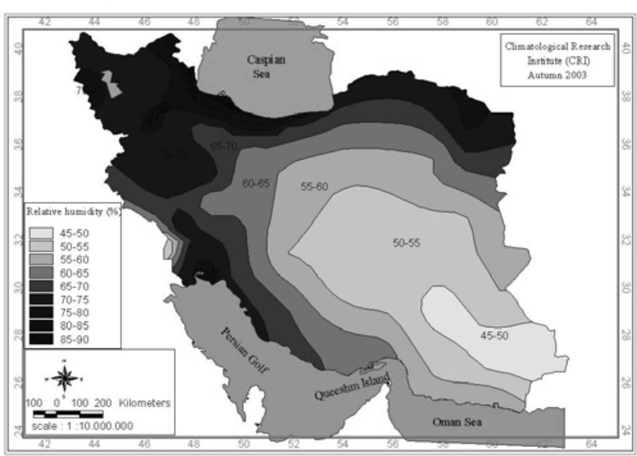

Figure 7. Spatial distribution of average relative humidity on January during long term period (1951-2000).

Iran contains six basins: Oromiyeh Lake, Caspian Sea, Gharehghom, Persian Gulf, Namamzar khaf and Kaviremarkazi, as shown in Figure 9. Table 1 has been filled out for the above mentioned basins, and Table 2 and 3 show the detailed and final scores of the six above-mentioned basins respectively. Oromiyeh acquired 69. On the other hand, the Kaviremarkazi Basin has the weakest condition for cloud seeding, as it acquired 46 from 100. The criteria table has also filled out for the other basins.

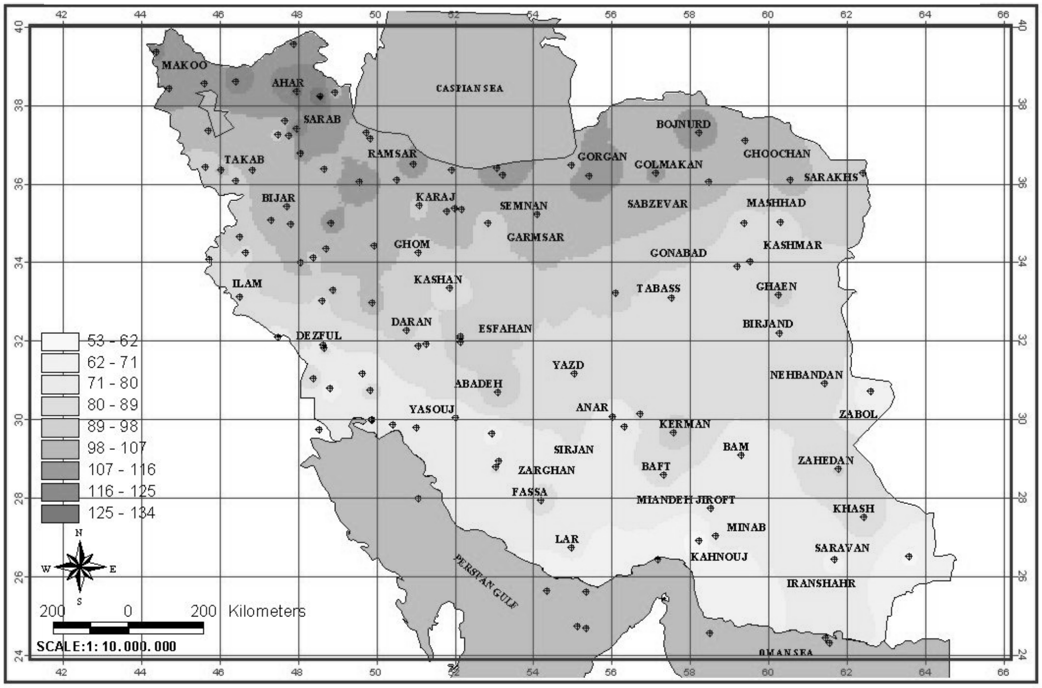

Figure 8. Annual average of cloudiness (3-6/8) over Iran during 1975-1995.

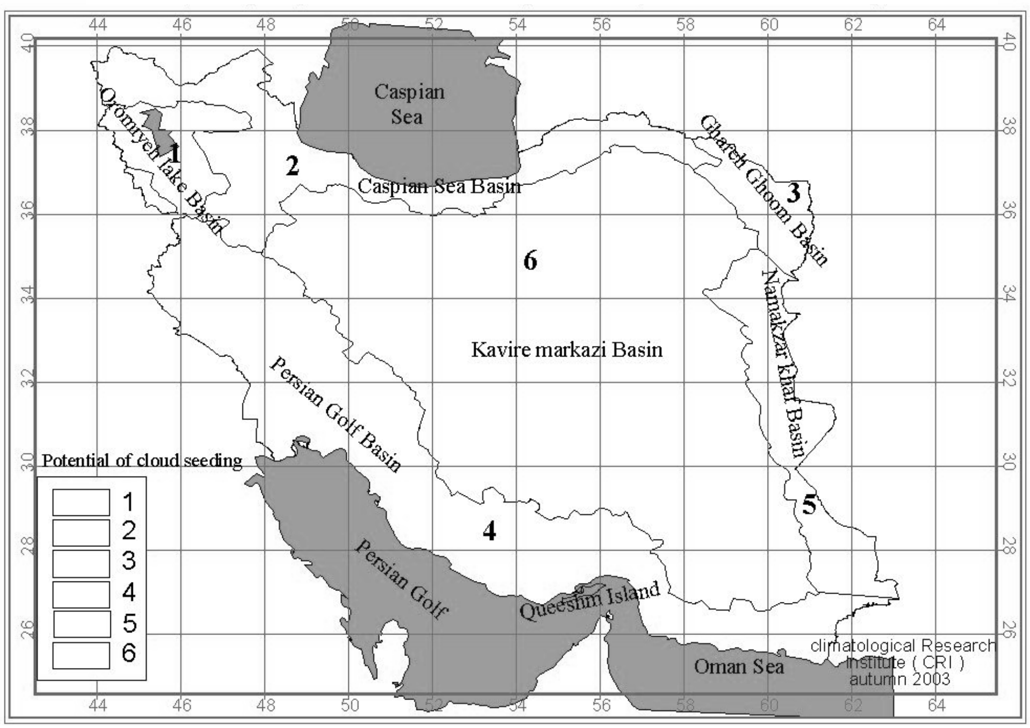

Figure 9. Classification of Iran's basins in view point of cloud seeding (1 is highest potential for cloud seeding 6 is lowest potential for cloud seeding).

Table 2. Detailed scores of six basins in view point of potential for cloud seeding in Iran

Basin Name	Oromiyeh	Ghareh Ghoom	Caspian Sea	Persian Gulf	Namak zar Khaf	Kavire Markazi
Physical characteristics of site						
1. Size	10	10	8	10	10	10
2. Degree of homogeneity	3	1	3	2	4	4
Characteristics of Precipitation						
3. Annual amount	6	6	2	2	0	0
4. Regime, including importance of ice phase	12	12	12	9	3	3
5. Prop. Liquid to solid at ground	10	10	10	10	10	10
6. Length of rainy season	1	0	1	2	3	4
			1			
Availability of Meteorological data						
7. Density of rain gauge network	0	2	0	0	4	0
8. Length of record	4	4	4	4	4	4
9. Other data (radar, rainysonde, etc.)	3	1	2	2	1	1
Facilities						
10. Airport, instrument, flight support, lack of flight restrictions	10	10	10	8	6	6
11. Communications	5	5	4	4	2	2
12. Working conditions	5	5	4	4	2	2
TOTAL	**69**	**66**	**60**	**56**	**49**	**46**

Table 3. Final scores of six basins in view point of potential for cloud seeding in Iran

Name of Basin	Score
Oromiyeh Lake	69
Ghareh Ghoom	66
Caspian Sea	60
Persian Gulf and Oman Sea	56
Namak zar Khaf	49
Kavireh - Markazi	46

The above results are the application of first stage of SSP. The stages 2 and 3 which have been mentioned in section 2, are under research in this project. The research into cloud and precipitation, climatology of the region and application of numerical modeling are required before field programs. For example, before cloud seeding field experiment in Kyushu Island in Japan, numerical modeling of liquid carbon dioxide seeding has been developed (Javanmard et al., 1998 a, b; 1999).

4. DISCUSSION AND CONCLUSION

Cloud seeding as a potential technology of precipitation enhancement is very closely linked to water resources management. In the last few years, operational programs have increased but now without a scientific research program supporting them (Bruintjes, 1999).

In the scientific community weather modification is still viewed as a somewhat controversial topic, Changnon and Lambright (1990) identified several problems and difficulties that have arisen during the conduct of weather modification experiments. According to Changnon and Lambright, based on their analyses of National Hail Research Experiment (NHRE) and the Sierra

Cooperative Pilot Program (SCCP), the major scientific controversies were a result of six factors.

These factors are: 1) proceeding with an inadequate scientific knowledge base, 2) a flawed project-planning process; 3) differing view between funding agencies and project scientists, 4) lack of continuing commitment by the principal agency conducting the experiment, 5) changes in project directors; and 6) poor performance by project directors. Because of the complex nature of precipitation enhancement experiments, it is important to review the terms of these six factors in order to attain certain results.

In order to conduct a scientific cloud seeding project, a feasibility study before the field experiment is one of the necessities. In this approach, the cloud seeding feasibility study has been conducted in IRIMO, the preliminary results of the project including first stage of SSP results has been presented. As it is mentioned above, the criteria tables were filled out for six basins as shown in Fig. 9. Applying all of the information of rainfall, temperature, snow coefficient, spatial distribution of rain gage stations, cloudiness data, climatic and synoptic conditions for every basin, it shows that northwest and north of Iran has high potential for cloud seeding compared to the center, south and east of Iran. The total scores of Oriomiyeh is 69 and Caspian Sea, with score 66, Gharehghoom with 60, Persian Golf with 56, Namakzare khaf with 49, and Kaviremarkazi with 46, has the weakest condition for cloud seeding in Iran (ASMERC, 2002).

REFERENCES

American Meteorological Society, 1992: Planned and inadvertent weather modification. *Bull. Amer. Meteor. Soc.*, **73,** 331–337.

Atmospheric Science and Meteorological Research Center, 2002: Report of weather modification studies project in Iran phase (I), rain enhancement feasibility study*.

BodaghJamali, J., Heidari, Javanmard, 2002: Report of fog dispersion experiment in Iran, climatological Research Institute (CRI)*.

BodaghJamali, J., S. Javanmard, N. Fukuta, A. M. Noorian, 2003: Improved numerical modeling of RETHIT and FILAS in LC seeding based on field experiment over over north Kyushu island (Japan), Proc. of 8th WMO Weath. Mod. Conf. Morocco.

Bruintjes, R. T., A review of cloud seeding experiments to enhance precipitation and some new prospects, *bull Amer. Meteor. Soc.* **Vol. 80**, No. 5, 1999.

Changnon S. A, and W. H. Lambright, Experimentation involving controversial scientific and technological issues: weather Modification as a case illustration. *Bull. Amer. Meteor. Soc.*, **71**, 334-344, 1990.

I. R. of Iran Meteorological Organization Technical Report of Cloud Seeding Project in Yazd, 1995*.

Internet resource; http: // www.world. Water – forums. Cors.

Internet resource; http:// www.johanseburg summit.org.

Javanmard, S., J. B. Jamali, GH. A. Kamali, Site selection study for cloud seeding in order to precipitation enhancement in I. R. of Iran, Proc. of 8th WMO Weath. Mod. Conf. Morocco. 2003.

Javanmard, S., K. Nishiyama, N. Fukuta, K. Wakimizu, Y. Suzuki, Numerical modelling for roll-up expansion of twin horizontal ice crystal thermals in liquid carbon dioxide seeding. *Proc. of the 14th Conf. On Planned and Inadvertent Wea. Mod. Everret, WA*, 622-625, 1998a.

Javanmard, S., N. Fukuta, K. Nishiyama, Y. Suzuki, Wakimiau, Numerical modelling of Low level horizontal penetration seeding of supercooled cloud with liquid carbon dioxide. *J. Fac. Agr. Kyush Univ., Japan*, **43** (1.2), 234-2550, 1998b.

Javanmard, S., Y. Suzuki, N. Fukuta, K. Nishiyama, Numerical Modelling for falling growth induced lateral air spreading of ice crystal thermal in liquid carbon dioxide seeding, *Proc. of the WMO Scientific Cont. on Wea. Mod. Chaian Mai, Thailand*, 367-370, 1999.

Ministry of Energy, Technical Report of Cloud Seeding Project, 1978*.

World Meteorological Organization, Weather Modification Program, Precipitation Enhancement Project, Report **No. 3,** 1976.

* Copies will be provided to interested readers.