Weather modification, solution and innovation to reservoirs water sustainable management (case study: ZayandeRoud reservoir)

Modification des conditions météorologiques, solution et innovation pour la gestion durable de l'eau des réservoirs (étude de cas : le réservoir de ZayandeRoud)

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Abstract. Climate change has had devastating effects on water resources in many countries. Many volumes of Iran's water resources have declined due to climate change. Meanwhile, the use of weather modification methods, especially cloud seeding, is a practical solution to adapt to the climate change impact. In Iran, consecutive droughts and climate change have reduced water resources of dams behind and in some cases, they have completely dried up. Nowadays, cloud seeding is used as the most cost-effective method for water harvesting in the world... The results of the evaluation of cloud seeding projects in most parts of the country indicate an average runoff increase of between 10% and 15% during the seeding periods. Zayanderud Dam is one of the big dams in Iran in the Zagros Mountain range its water resources have been significantly reduced by overdraft and climate change. Cloud seeding operations have been performing for many years in the Charmahal and Bakhtiari catchment, which are located upstream of the ZayandeRoud reservoirs as new method to sustainable water resources management of dams. In this article, the results of runoff production by cloud seeding operation will be noted in the ZayandeRoud Dam for 10 years Non-consecutive (2006 – 2016).

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Résumé. Le changement climatique a eu des effets dévastateurs sur les ressources en eau dans de nombreux pays. De nombreux volumes des ressources en eau de l'Iran ont diminué en raison du changement climatique. Parallèlement, l'utilisation de méthodes de modification des conditions météorologiques, en particulier l'ensemencement des nuages, est une solution pratique pour s'adapter à l'impact du changement climatique. En Iran, les sécheresses consécutives et le changement climatique ont réduit les ressources en eau des barrages et dans certains cas, ils se sont complètement asséchés. De nos jours, l'ensemencement des nuages est utilisé comme la méthode la plus rentable pour la récupération de l'eau dans le monde. Les résultats de l'évaluation des projets d'ensemencement des nuages dans la plupart des régions du pays indiquent une augmentation moyenne du ruissellement comprise entre 10 % et 15 % au cours de la période de semis. Le barrage de Zayanderud est l'un des grands barrages d'Iran dans la chaîne de montagnes de Zagros. Ses ressources en eau ont été considérablement réduites par le découvert et le changement climatique. Des opérations d'ensemencement de nuages se déroulent depuis de nombreuses années dans les bassins versants de Charmahal et Bakhtiari, qui sont situés en amont des réservoirs de ZayandeRud, comme nouvelle méthode de gestion durable des ressources en eau des barrages. Dans cet article, les résultats de la production de ruissellement par opération d'ensemencement des nuages sont présentés pour le barrage de Zayanderud pendant 10 ans non consécutifs (2000 - 2016).

Introduction

Iran has a hot, dry climate characterized by long, hot, dry summers and short, cool winters. The climate is influenced by Iran's location between the subtropical aridity of the Arabian Desert areas and the subtropical humidity of the eastern Mediterranean area. January is the coldest month, with temperatures from 5°C to 10°C, and August is the hottest month at 20°C to 30°C or more.

In most of the areas, summers are warm to hot with virtually continuous sunshine, but high humidity on the southern coastal areas of the Persian Gulf. Daily Temperatures can be very hot; on some days temperatures can reach easily 40°C or more, especially along the Persian Gulf and Oman Sea which causes a danger of heat exhaustion.

About 70 percent of the average rainfall in the country falls between November and March; June through August are often rainless. Rainfall varies from season to season and from year to year. Precipitation is sometimes concentrated in local, but violent storms, causing erosion and local flooding, especially in the winter months. A small area along the Caspian coast has a very different climate; here rainfall is heaviest from late summer to mid-winter but falls in general throughout the year.

Therefore, Iran Can be divided into 3 major climate areas (Fig. 1):

- Mediterranean climate, which covers the narrow strip alongside Caspian Sea in the north
- Cold dry climate in the mountain areas of the west and Northwest,
- Arid (or desert) and semi-arid climate, which covers most of the country, especially the central plateau of Iran.
- Also, the average long-term precipitation of the country is 220 mm, with a non-uniform spatial and temporal distribution across the country.

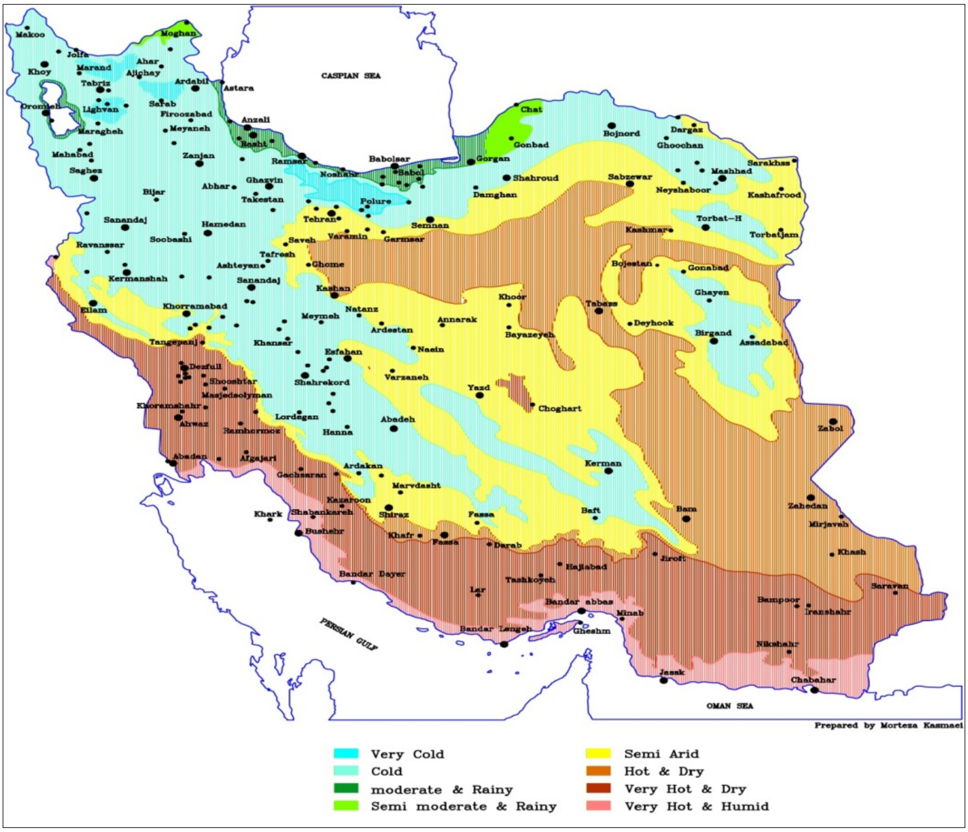

Fig. 1. Iran climate map.

Weather modification- A weather modification (also known as weather control) is the act of intentionally manipulating or altering the weather. The most common form of weather modification is cloud seeding, which increases rain or snow, usually for the purpose of increasing the local water supply.[1-3] Weather modification can also have the goal of preventing damaging weather, such as hail or hurricanes, from occurring; or of provoking damaging weather against the enemy, as a tactic of military or economic warfare like Operation Popeye, where clouds were seeded to prolong the monsoon in Vietnam. [2]

Also, existing literatures shows that cloud seeding technology is an economic option for water harvesting, compared with other possible solutions like desalination technology, wastewater treatment, artificial recharge and etcetera. For instance, Shivaji (in two thousand five) stated that costs of cloud seeding operations are about fifteen US dollars per one thousand cubic meters of enhanced water. Table 1 shows these cases.

Table1. Costs of different methods for water harvesting (Source: Shiva, 2005)

Solution	**Cost** (US$ per 1000 cubic meters)
Desalination	2000
Inter-basin transfer	400
Artificial Recharge	230
Wastewater Treatment	220
Cloud seeding	**15**

The goal of this research is introduction of cloud seeding project in Iran and assessment of rainfall increasing to Zayanderoud basin.

1. Methodology

1.1 Weather modification operations in Iran

The process of performing the cloud seeding operations is as follows (Fig. 2): at the first, based on output of weather forecast models, current weather data and weather radar & satellite images are decided to perform operations and the right time and place for seeding is determined. During the flight, the operational team will closely monitor the cloud system with the help of airborne sensors and real-time information sent from the Air Operations Control Center and begins to seeding. Immediately after the operational season all seeding flights are evaluated.

Fig. 2. Schematic of the procedures included in the conduction of a cloud seeding operation in Iran.

Table 2 shows Information on operational flights in Zayandehrud catchment area from 2006 to 2017. As table shows most operation flights perform in 2008-2009 with 36 flights. In 2010-2011 we don't have any flight in the basin of Zayandehrud Due to a number of environmental factors. Operation season start from November to April.

Table 2. Information on operational flights in Zayandehrud catchment area from 2006 to 2017.

Row	Operation Time	Number of flight in target area
1	2006-2007	23
2	2008-2009	36
3	2009-2010	11
5	2010-2011	0
6	2012-2013	11
7	2015-2016	14
8	2016-2017	10

1.2 Equipment and services

The cloud seeding programs in Iran include the airborne method for the cold clouds, and the airplanes are equipped in order to be able to seed above and inside the clouds. The material used in Iran cloud seeding programs, is silver iodide for seeding the convective clouds and liquid nitrogen for seeding the stratiform clouds. Silver iodide acts as ice nuclei and with the initiation of the Bergeron's process, leads to the production and enhancement of the ice crystals and the subsequent speed up of the precipitation process. Liquid nitrogen also acts as a coolant and with decreasing the environment's temperature, leads to the freezing of the liquid droplets inside the cloud and forming the ice crystals (see the first chapter). Figure 3 shows two aircrafts dedicated to the cloud seeding in the Yazd International airport and in part B, Liquid propane tank (cloud seeding agent).

There are two Antonov-26 aircrafts which are used for the cloud seeding in Iran. The equipment mounted on these two aircrafts includes two sets, one for sensing the meteorological quantities, and another for injecting cloud seeding material inside the clouds.

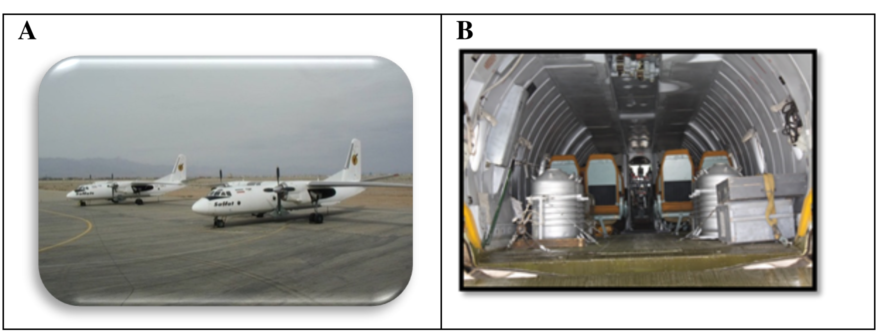

Fig. 3. A) Two aircrafts dedicated to the cloud seeding in the Yazd International airport. B) Liquid propane tank (cloud seeding agent).

2. Result

2.1 Evaluation

Determination of control stations: Maximum destination between stations of control region and target region's border should be 50 km to 100 km and should be located in areas which continentally are similar to the target region. Precipitation volume of January, February, April and December of 2009-2010 was measured through kriging method and related raster maps were made through normal kriging method and total volume of precipitation for target region was specified. Time series of monthly precipitation for each station for exact time periods was provided and was take in to regression model, as independent transitive.

2.2 Historical regression approach

According to national and international evaluations, historical regression is one of the most reliable approaches in cloud seeding project's evaluation. In this approach, best regression proportion between control and target region during years which no cloud seeding has been done, is determined so that having precipitation volume of control region, the precipitation of target region can be prospected. In this approach, proportion data between control and target region can be very variable and possibility of estimating the changes to be accidental is probable. One of preparations which should be done before evaluation is to normalize monthly precipitation data. If the actual data is not normalized, the presumption of mistakes in adherence of changes in regression line from normal line will be common. The other point which should be considered precisely is equality of time scale between control and target region. If the time scale in both regions is not equal, correlation and reliable estimations are doubted.

2.3 Determination of precipitation in target area

First, raster maps for each month of the year (1973-2006) were generated using interpolation kriging method and then precipitation values for each year were extracted from these maps. In the next step, the precipitation volume of December, January, February and April for target stations were calculated and (using interpolation method) used as dependent variables for estimation of precipitation volume of target regions.

2.4 Determination of confidence levels:

In creditable sources, the confidence level of results of cloud seeding projects is determined to be 95%. So, to determine that in confidence level of 95%, the increase of precipitation is caused by cloud seeding or any other factor has effect on this increase, some other confidence tests will be done on results.

2.5 Determination of confidence intervals:

The determination of confidence intervals of natural changes in precipitation of region is achieved through statistic methods. For better understanding of effect of confidence intervals on confidence of results, it can be said that if precipitation volume in target region (seeding materials affected area) is higher than prospected volume, it means that this increase (with confidence of 95%) is caused by cloud seeding project and if precipitation volume is lower than minimum prospected volume, it means that (with confidence of 95%) the cloud seeding project has caused reduction of precipitation, also if the precipitation is within prospected volume, it means that the effect of cloud seeding project can't be judged. Table 2 shows Information on evaluation of projects in Zayandehrud catchment area from 2006 to 2017. As table 3 shows Number of months evaluated in first column, in inter zayanderoud basin, we have operated between from 4 to 6 month. Only in year of 2012-2013, we operated 6 months. Number of flights, month to depend on several conditions: weather opportunity, flight condition, management decision and… second column shows actual rainfall in the target area (billion cubic meters), most rainfall increasing is related to 2006-2007. Third column shows Expected rainfall in the target area (Billion cubic meters), as in last part explain about methods, expected rainfall calculate with historical rainfall that records in station in my target and control area. Fourth column shows volume of harvesting water via cloud seeding project that in 2015-2016 has most value. The end of column shows increased rainfall (Percentage), most increase rainfall via cloud seeding projects related to 27% in 2009-2010. For evaluating of 2016-2017 cloud seeding project, we have used wrf ensemble model that need to time because of Complex processes of implementing the ensemble model. There for unfortunately after 4 years we couldn't finish this process.

Table 3. Information on operational flights in Zayandehrud catchment area from 2006 to 2017.

Row	Operation time	Number of months evaluated	Actual rainfall in the target area (billion cubic meters)	Expected rainfall in the target area (Billion cubic meters)	The amount of water extracted (billion cubic meters)	Increased rainfall (Percentage)
1	2006-2007	5	40.18	35.24	4.84	13.7
2	2008-2009	4	19.37	16.28	3.08	18.96
3	2009-2010	5	3.3	2.6	0.7	27
4	2010-2011	4	9.23	8.29	1.029	12
5	2012-2013	6	12.82	10.28	2.52	24.6
6	2015-2016	5	18.4	24.2	6.4	22
7	2016-2017	Under evaluated				

Table 4 shows the results of our analysis on enhanced volumes of water and costs of cloud seeding activities for the Central Iran Cloud Seeding Projects during two thousand fifteen (2015). This project covered five provinces of Yazd, Kerman, Fars, Isfahan and Chahar Mahan and Bakhtaran with the total area of about thirty-five million hectares. As shown in this table, total volume of enhanced water has been estimated to about two thousand sixteen (2016) million cubic meters. Considering the total costs of cloud seeding operations, an average of eighteen point two Iranian Rails has been paid for each cubic meter of enhanced water. This is equal to about point five cent of US dollars, indicating that cloud seeding technology is an economic solution of water harvesting in arid regions.

Table 4. Enhanced Volumes of Water and Cost Analysis for the Central Iran Cloud Seeding Activities during 2015.

Province	Volume of Enhanced Water (MCM)			Cost of Enhanced Water (IR. Rials per cubic meter)	
	Surface Water	Ground Water	Total	Surface Water	Total
Yazd	72.3	27.3	99.6	162.2	82.5
Kerman	186.9	112.6	299.5	29.4	12.7
Fars	112.8	141	253.8	58.6	26.3
Isfahan	133.6	111.1	244.7	59.3	40.6
Chahar mahal va Bakhtiyary	823.9	295	1118.9	5.8	4.9
Total/Average	**1329.5**	**1329.5**	**2016.5**	**27.5**	**18.2**

Conclusion

The results of the present research showed that cloud seeding has been able to play an important role in water supply of Zayandehrud Dam, so that with the cloud seeding in the upstream of Zayandehrud Dam watersheds for several years, several million cubic meters of runoff has been produced and this is a way to reduce the adverse climate change impact. Investing in weather modification and doing it on a long-term and consecutive basis, as is done in many countries around the world, is one of the most cost-effective ways to produce water.

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