Meta-heuristic ant colony optimization technique to forecast the amount of summer monsoon rainfall: skill comparison with Markov chain model

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Introduction

Indian summer monsoon is a key component of the climate system, both in regards to its strong interaction with other modes of variability and its enormous socioeconomic impacts

Forecasting summer monsoon rainfall with precision becomes crucial for the farmers to plan for harvesting in a country like India where the national economy is mostly based on regional agriculture.

Objectives

In the present study the Ant Colony Optimization (ACO) technique is implemented in forecasting the amount of summer monsoon rainfall over Kolkata, India with 24 hrs lead time.

The conventional statistical Markov Chain model (MCM) is utilized to assess the skill of the ACO technique.

Data

The record and data of summer monsoon rainfall are collected from regional meteorological centre (RMC), Kolkata, India during the period from 1998 to 2015 on daily temporal scale for the months of June, July, August and September (JJAS) for the present study. The record and data from 2008 to 2015 are utilized for validation of the result.

Methodology

- Ant Colony Optimization
- Markov Chain Method

Ant Colony Optimization

ACO technique takes inspiration from the foraging behaviour of ant species.

The ants deposit ***pheromone*** on the ground in order to mark a favourable path that should be followed by other members of the colony (Dorigo 1990) .

What the pheromone is!!

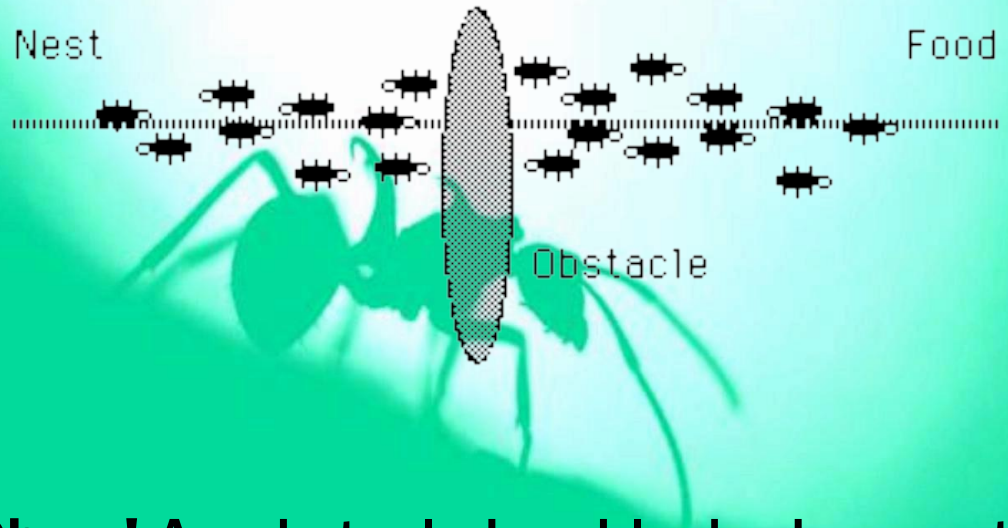
In real life, pheromone refers to the chemical material that an ant spreads over the path it goes and the level of it changes over time by evaporating.

On the other hand, in ant colony optimization, pheromone is a parameter. The amount of this parameter determines the intensity of the trail (Dréo et al., 2006).

Naturally Observed Ant Behavior

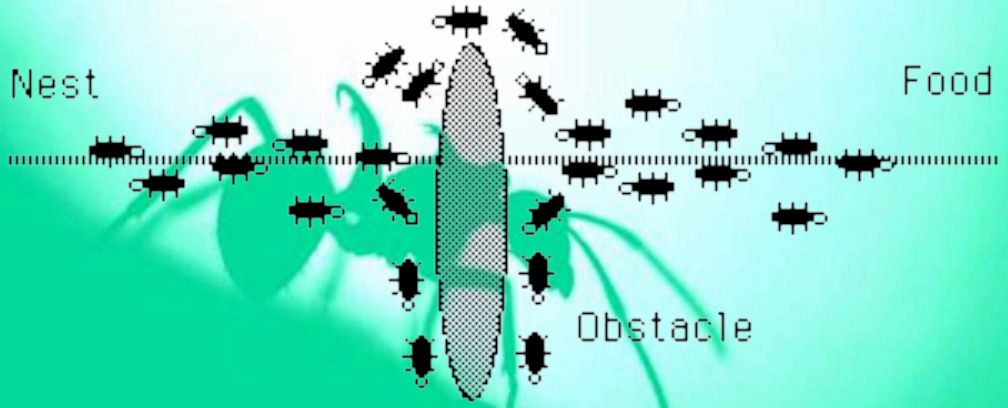
Where do we go?

Naturally Observed Ant Behavior



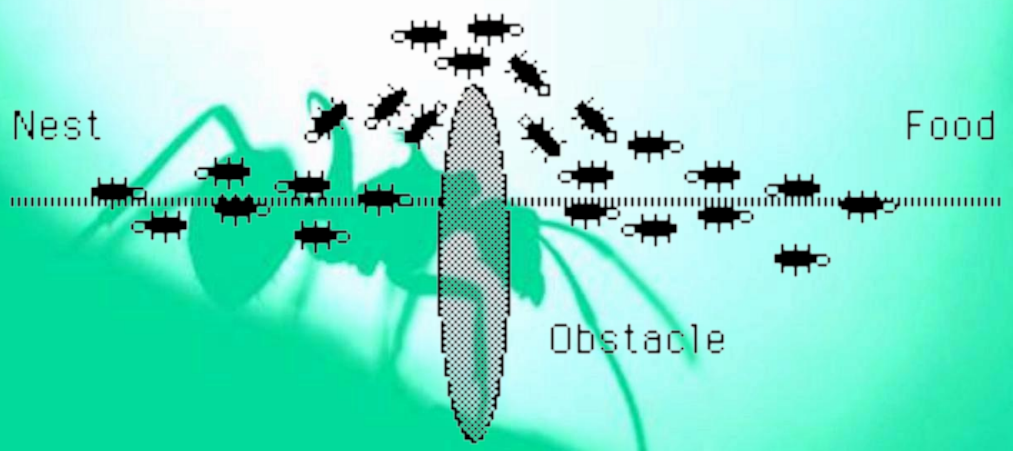
Oh no! An obstacle has blocked our path!

Naturally Observed Ant Behavior

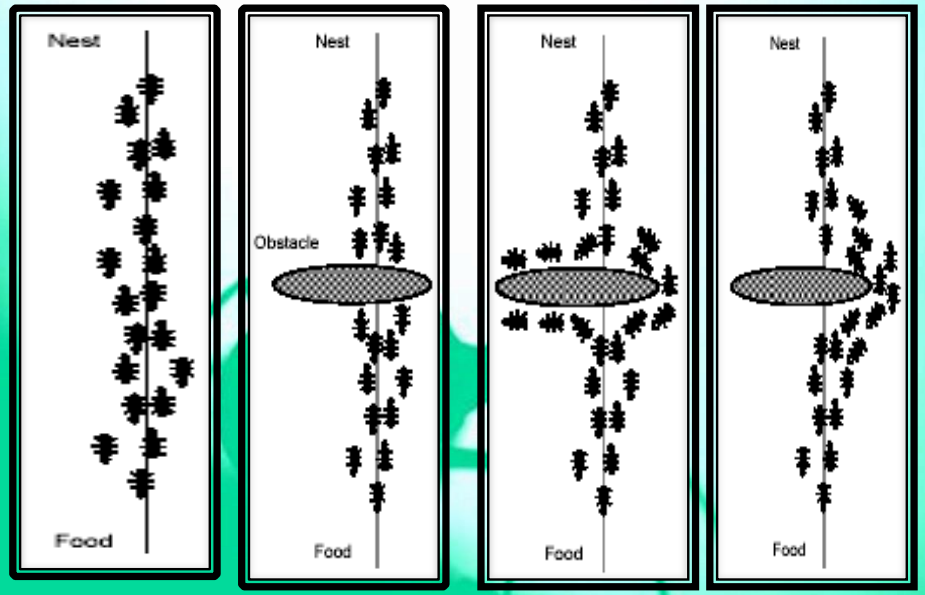


Where do we go? Everybody, flip a coin.

Naturally Observed Ant Behavior



Shorter path reinforced.



The short bridge receives , therefore, pheromone earlier than the long one and this fact increases the probability that further ants select it rather than the long one

Ant Colony Optimization

It has been established from the double - bridge experiment (Deneubourg et al.) that the concentration of pheromone deposition is inversely proportional to the path length between the nest and the food-source, which is mathematically represented as:

$$\Delta \tau_{ij}^{k} = \frac{1}{L_k}$$

The amount of pheromone deposition if ant k, travel on edge i, j.
L_k = the path length = (ant hill value - critical value).

Goss et al. (1989) developed a model of the observed behaviour assuming that at a given moment in time m_1 ants have used the first bridge and m_2 the second one, the probability p_1 for an ant to choose the first bridge is:

$$p_1 = \frac{(m_1 + k)h}{(m_1 + k)h + (m_2 + k)h}$$

Where parameters k and h are to be fitted to the experimental data. $P_2 = 1 - P_1$
Monte Carlo simulations showed a very good fit for k ≈20 and h≈ 2

Markov Chain Model

The simplest kind of discrete random variable pertaining to dichotomous (yes / no) forecast is made through the Markov chain model (MCM). A two state MCM is a statistical model for the persistence of binary events. The occurrence or non occurrence of summer monsoon rainfall on a given day is a simple meteorological example of a binary random event.

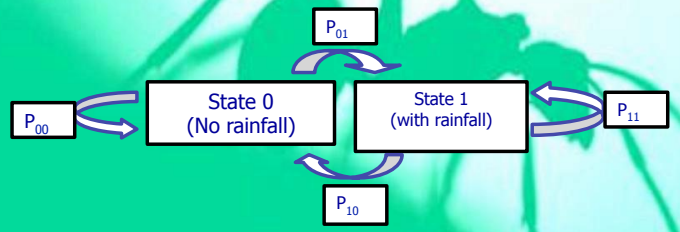


Figure 1 Two states, first order Markov Chain Model

$$P_{00} + P_{01} = 1$$

$$P_{10} + P_{11} = 1$$

$$P_{01} = \frac{n_{01}}{n_{o\cdot}} = \frac{n_{o1}}{n_{oo} + n_{01}}$$

$$P_{11} = \frac{n_{11}}{n_{1\bullet}} = \frac{n_{11}}{n_{10} + n_{11}}$$

Implementation

Rainfall days
With rainfall amount

⇒

Ranges of rainfall as per IMD norm

⇒

Ranges of monsoon rainfall over Kolkata using statistical method

⇩

Different Ranges of monsoon rainfall using ACO technique in terms of pheromone deposition

⇩

Estimation of critical value and ant hill value for each of the ranges

⇩

The pheromone deposition for the path has been calculated

A range of values of pheromone deposition is obtained applying optimization procedure

⇩

Transition probability of frequency of rainfall for successive two days (Day 1 and Day 2) using ACO and MCM

⇩

Identification of most pertinent combination of monsoon rainfall for successive 2 days (Day 1 and Day 2) using histogram plot

⇩

Validation with observation and error calculation for skill assessment forecast

Ranges of the amount of monsoon rainfall as per IMD norm

Range	Descriptive Term used	Rainfall amount in mm	
		minimum	maximum
R1	No rain	0	0
R2	Very light rain	0.1	2.4
R3	Light rain	2.5	7.5
R4	Moderate rain	7.6	35.5
R5	Rather heavy rain	35.6	64.4
R6	Heavy rain	64.5	124.4
R7	Very Heavy rain	124.5	244.4
R8	Extremely Heavy rain	≥ 244.5	
R9	Exceptionally Heavy rain	When the amount is near the highest recorded rainfall at or near the station for the month or the season. However, this term will be used only when the actual amount of rainfall exceeds 12 cm.	

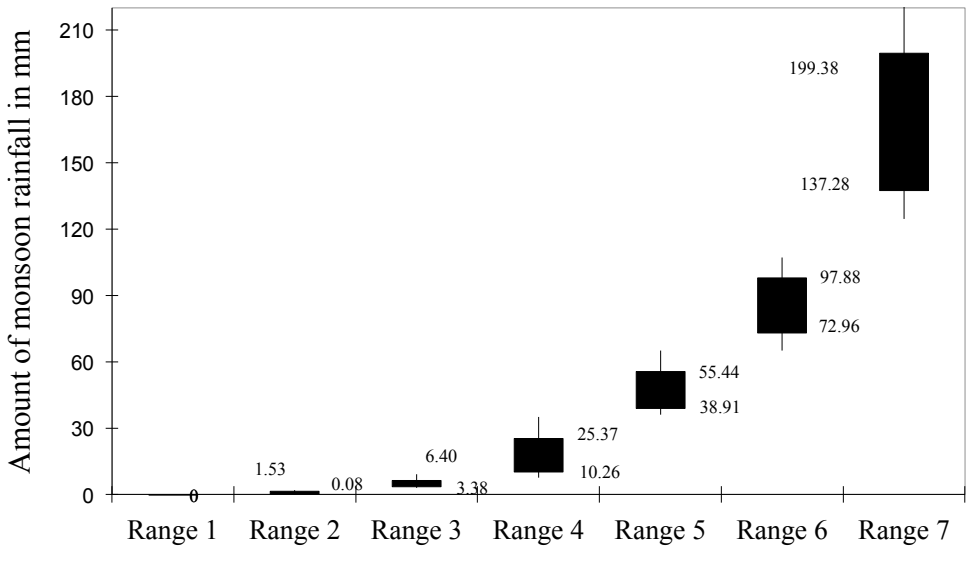


Figure 2 Blot plot showing the different ranges of monsoon rainfall amount over Kolkata using statistical method

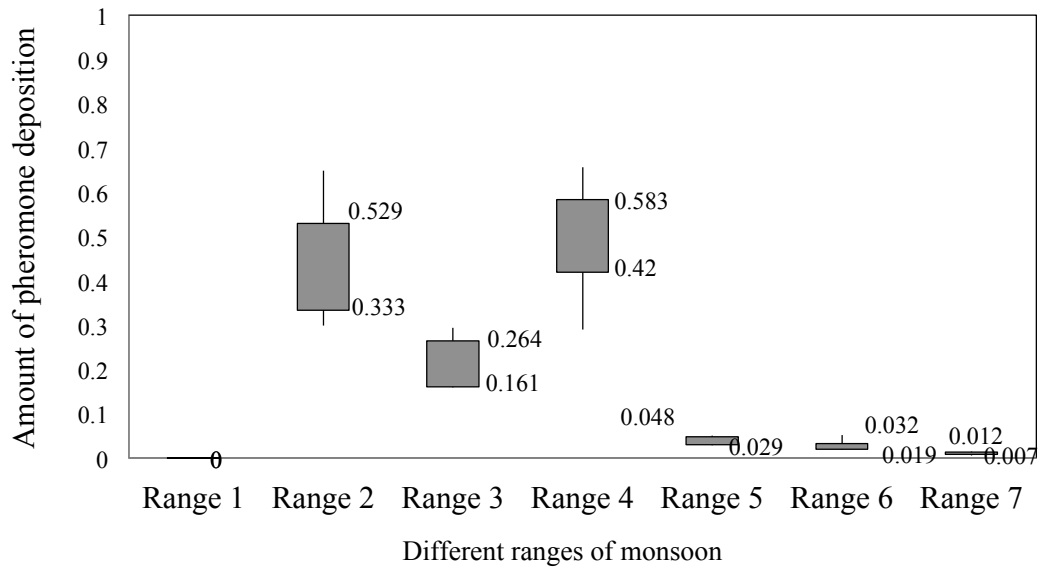


Figure 3 Box plot showing the different ranges of monsoonal rainfall amount in terms of pheromone deposition over Kolkata using ant colony optimization technique

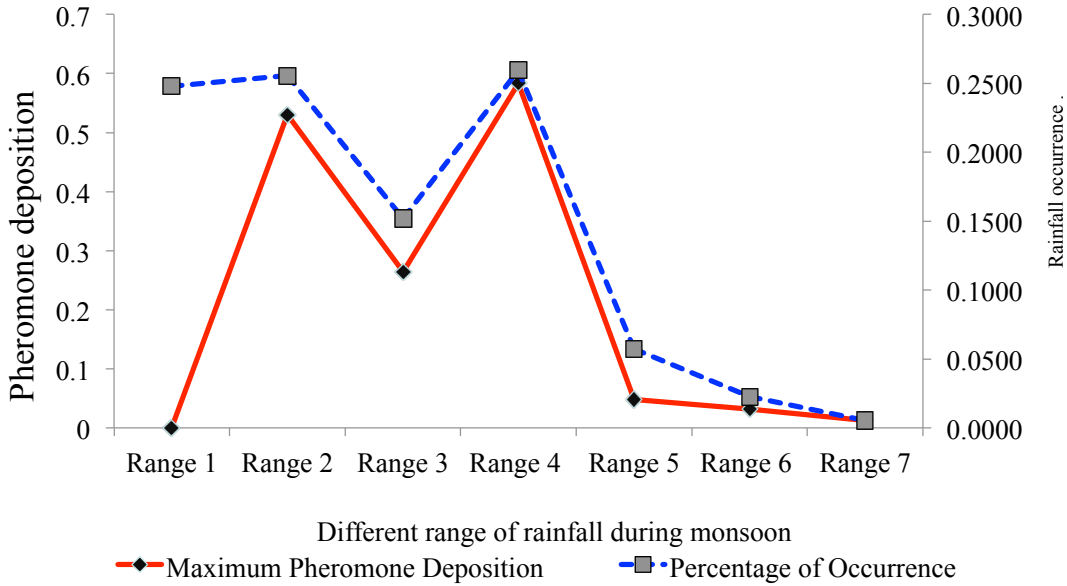


Figure 4 The maximum pheromone deposition along with the rainfall occurrences with different ranges of monsoon rainfall over Kolkata

Results

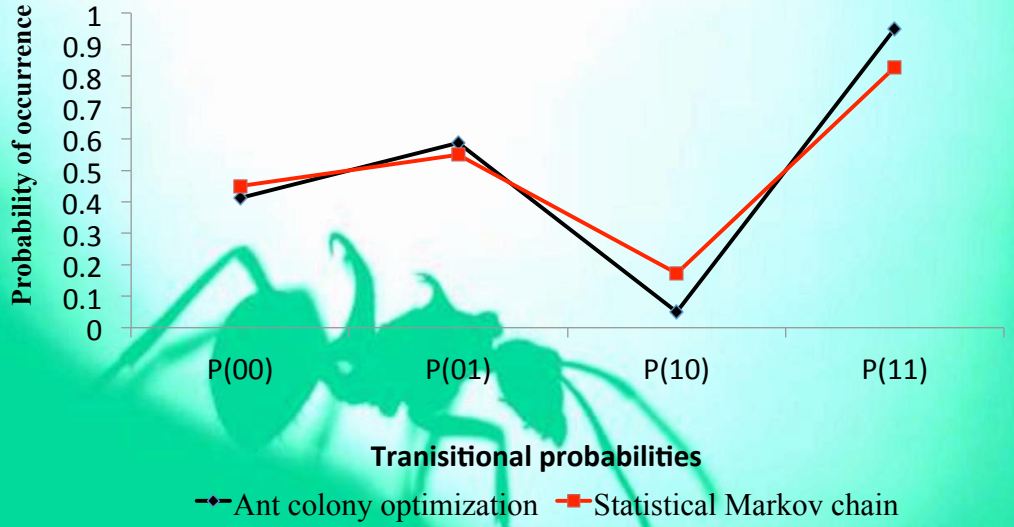
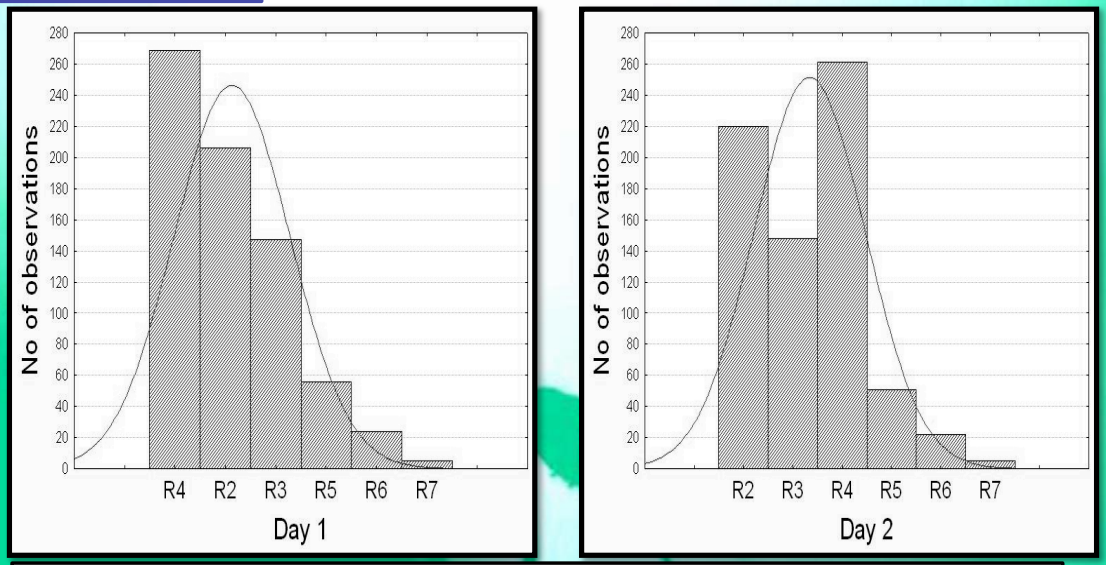


Figure : Transitional probability using for the occurrences of rainfall for successive two days (Day 1 and Day 2) during monsoon season using ant colony optimization technique and statistical Markov chain method over Kolkata

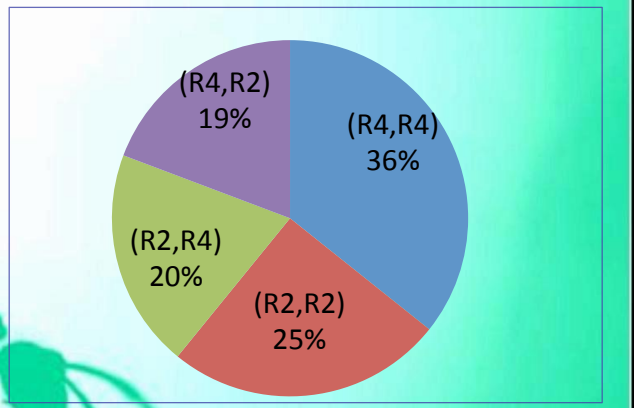
Results



The diagram showing the maximum occurrences of rainfall in (a) Day 1 and (b) Day 2 in histogram plot

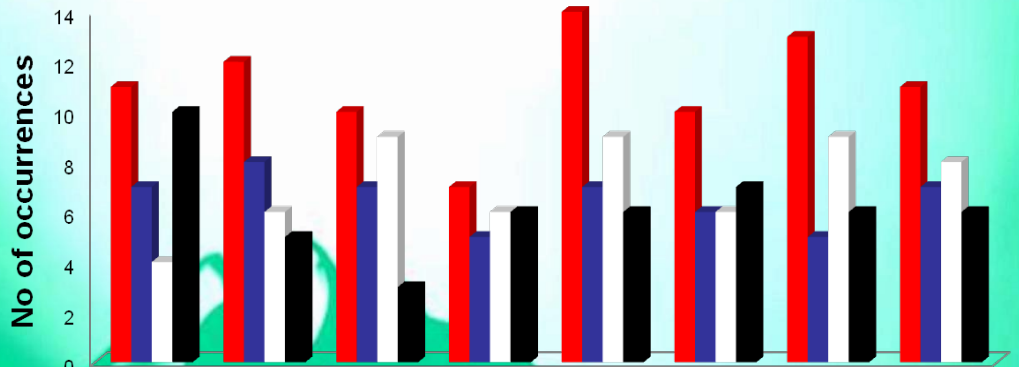
Results

- Combination 1: R4, R4
- Combination 2: R4, R2
- Combination 3: R2, R4
- Combination 4: R2, R2



Maximum occurrences of rainfall with different combinations using range 4 and range 2 throughout the summer monsoon season over Kolkata

Validation



	2008	2009	2010	2011	2012	2013	2014	2015
R4, R4	11	12	10	7	14	10	13	11
R2, R4	7	8	7	5	7	6	5	7
R4, R2	4	6	9	6	9	6	9	8
R2, R2	10	5	3	6	6	7	6	6

The diagram validation the most dominating combination of the amount of rainfall for consecutive two days (Day 1 and Day 2) is (R4,R4) in the year 2008 to 2015 throughout the monsoon season (JJAS) over Kolkata

Validation

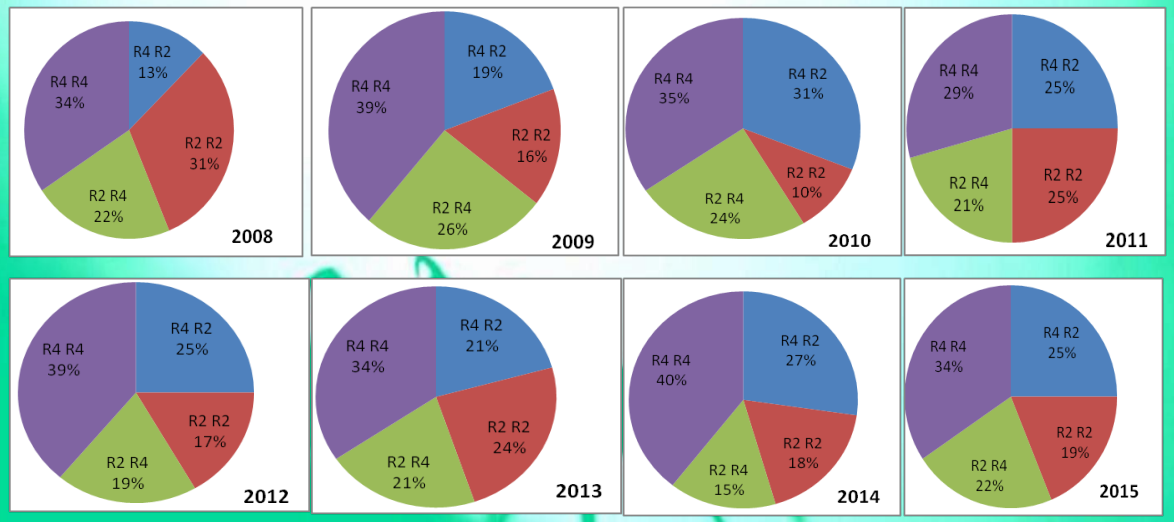
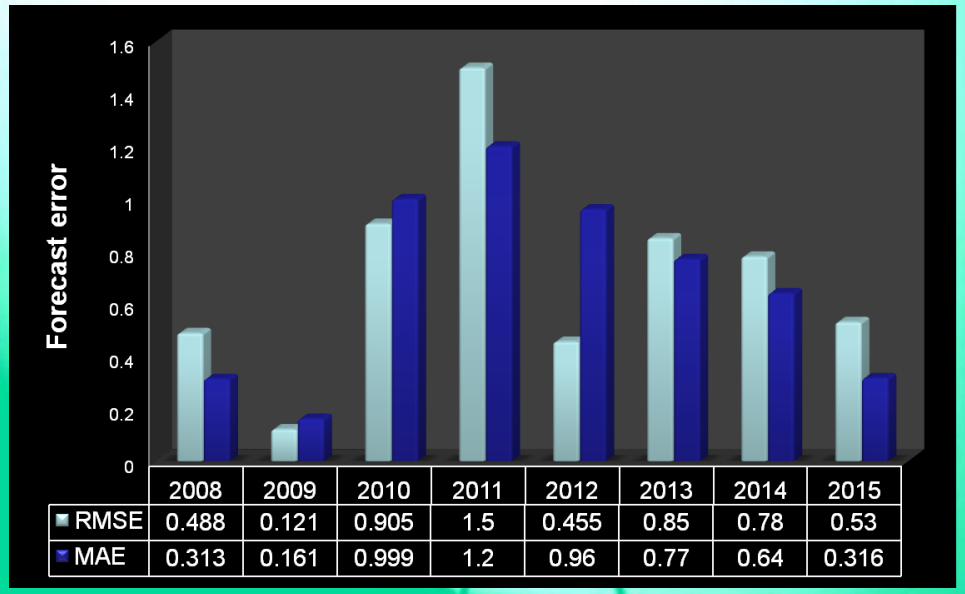


Figure The diagram validating the most dominating combination of amount of rainfall for consecutive two days (R4, R4) from 2008 to 2015 throughout the monsoon season (JJAS) over Kolkata

Validation



	2008	2009	2010	2011	2012	2013	2014	2015
RMSE	0.488	0.121	0.905	1.5	0.455	0.85	0.78	0.53
MAE	0.313	0.161	0.999	1.2	0.96	0.77	0.64	0.316

Different error matrices in predicting the maximum occurrences of the most dominating combination of rainfall amount (R4,R4) of monsoon rainfall over Kolkata during 2008 to 2015

Comparison of present study with other existing models/ methods

	Error
Markov Chain Model (MCM) **Little et al. (2009)**	MAE -1.9
Stochastic model (SM) forecast **(Sanso and Guenni 1999)**	MAD→17.38 to 18.48
Artificial neural network (ANN), a five-neural network architectures Model forecast **(Singh and Borah 2013)**	PE→7.67
Numerical Weather Prediction model (multimodel super ensemble and operational NWP forecast **(Mishra and Krishnamurti 2007)**	RMSE→1.25 to 2.60
Ant colony optimization (ACO) model forecast (**present study**)	RMSE→0.1 to 1.5 MAE→0.16 to 1.2

Summery

- The most dominant combination is P (1, 1).
- The most significant combination of rainfall over Kolkata during summer monsoon is evaluated
- Maximum occurrences of rainfall are found to be within the categories (R4, R4).
- The pheromone concentration on the other hand remains within the range of 0.42 – 0.58 indicating the maximum amount of pheromone deposition.
- ACO technique, therefore, may be used as an operational model for forecasting the frequency of rainfall as well as its ranges over Kolkata during the summer monsoon season.

Thanks