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Research Article

RAINFALL COMPARISON OF AUTOMATIC WEATHER STATIONS AND MANUAL OBSERVATIONS OVER BIHAR REGION

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ABSTRACT
The study discusses the comparison of 24 hour accumulated rainfall from manual and automatic rain gauges in 15 collocated stations of Bihar region. Results show that nine stations have bias within ±6 mm except Jahanabad, Monghyr, Rohtas, Muzaffarpur, Darbhanga and Sabour districts which have bias within ±20 mm. The correlation coefficients between two data sets of all the stations are strong and positive. The t test shows that the difference between means of two data sets is not statistically significant at 95 % confidence. The scores of probability of detection (POD) are strong and false alarm rate (FAR) is appreciably low almost for all the stations. It has been observed from the error structure analysis that usability of the rainfall data from AWS in day to day forecasting of all the stations over Bihar region are more than 75 % for all the stations.

Keywords: *Rainfall, Manual Observation and Automatic Weather Station /Rain Gauges*

INTRODUCTION
Precipitation is the key component of the policy and strategic planning activities the country. It is used in hydrological modeling and water balance. The state of Bihar is located in the eastern part of the Republic of India. It covers an area of 94,163 square km bounded by 24.2 $^\circ N$ to 37.31 $^\circ N$ latitude and 83.20 $^\circ E$ to 88.18 $^\circ E$ longitudes. The state has meteorologically only one sub-division with 38 divisions with three agro-climatic zones (figure 4). A network of 1350 Automatic Raingauge Stations (JINYANG make) is under installation by IMD during the year 2008-10 across India. Each ARG Station is configured to measure Hourly rainfall and Cumulative rainfall for the day. In Second Phase of IMD Modernization, a network of 2250 Automatic Raingauge Station (ARG) will be installed by IMD during 2011-2012 across India. By seeing the importance of rainfall data India meteorological department (IMD) in its modernization initiative there is a plan of installing 2000 AWS and 4000 ARGs all over the India in a phased manner during next 5 years.
Rainfall is a highly variable parameter in space and time as the heterogeneities on local scale in land surface features (hills) rivers, vegetation etc. affect its distribution. It is also a very important parameter for agricultural operations, water resource management and as well as result in hydro-climatic disasters on local and regional scales**.** Rainfall measurement plays a key role in meteorological, climatological applications and can be used to calibrate radar rainfall estimation algorithms (Anagnostou and Krajewski, 1998, 1999a, b). Several studies for comparison of automatic rain gauge data with the manual observations have been done in the past by Geeta and Panda (2014) for Karnatka region and Mohapatra *et al.,* (2011) for its utility in study the synoptic disturbances.

MATERIALS AND METHODS
Data and Methodology
The IMD AWS /ARG data has been taken from meteorological centre Patna and to make continuity Bihar state AWS data also utilized for the study. The rainfall sensor is tipping bucket type and can measure 0-1023 mm/hr with accuracy of ±5 mm. To make the comparison more meaningful collocated stations data is utilized for the present work. Manual rain gauge data 0830 hours IST of day 1 to 0830 hours IST of day 2. This 24 hours accumulated rainfall data is compared with the AWS/ARG data of the same accumulation time. Monsoon season (June to September) is the main rainy season for Bihar; hence

monsoon 2014 season data is used for comparison. The bias between the two data sets is calculated by the difference of conventional or manual and AWS measurements (bias= $Obs_{conventional} - Obs_{aws}$).

Verification strategy of rainfall forecast is given below:

Correct	Diff ≤ 25% of manual data
Usable	25% of AWS/ARG < Diff ≤ 50% of manual data
Unusable	Diff > 50% of manual data

(Diff is the absolute difference between manual and AWS/ARG rainfall)

Besides, various standard skill scores like Probability of Detection (POD), False alarm rate (FAR), Missing rate, Correct Non-occurrence (C-Non), Critical Success Index (CSI), Bias for Occurrence (Bias), Percentage correct (Pc), True skill score (Tss), Heidke skill score (Hss) have also been used in comparison of the AWS data with manual observations.

RESULTS AND DISCUSSION

A stainless steel tipping bucket (TB) rain gauge is used for measurement of rainfall volume in automatic rain gauges (ARGs). Most of the ARGs are JINYANG make and in automatic weather stations AWS) it is Sutron make with resolution 0.5 mm. The collector diameter is 20 cm and the resolution of the gauge is 0.5 mm. Thus, 15.7 cm3 (product of collector area and resolution) of rain water corresponds to 0.5 mm of rainfall. The large collector area helps prevent the loss of rainfall due to evaporation.

Several studies showed that TB gauge data are corrupted by errors, both random and systematic (Sevruk and Lapin, 1993). The systematic error is the most significant source of error and includes losses due to wind, wetting, evaporation, and splashing. Transforming the time-recorded number of tips into rainfall intensities can be made on different time scales to provide rainfall data products for numerous applications (Habib *et al.*, 2001). The AWS or ARG stations over Bihar region are dispersed at different locations in which some of them are far apart and some are nearly correlated with the part time or departmental observatories. Some of the hydro-meteorological ground truth data is collected through block level or universities employees. These employees are paid some emoluments for these data collections. Sometimes accuracies are affected due to non skilled staff, or instrumental errors. The collocated distance feasibility analysis is given in table 1 (a) and table1 (b) gives the collocated stations used for the present study.

The various skill scores between the two data sets along with the permissible use analysis of the AWS/ARG data is given in table (2). Table 3 gives the significant analysis at 95 % significance by computing p values and various other parameters. The scatter diagram between the AWS/ARG and manual (actual) data sets of all the 15 stations in figures 1 (a-o). Figures 2 (a-k) shows the permissible AWS/ARG rainfall usage in day to day weather forecasting and various skill scores, which are given in table (2). Results show that nine stations have bias within ±6 mm except Jahanabad, Monghyr, Rohtas, Muzaffarpur, Darbhanga and Sabour districts which have bias within ±20 mm. The correlation coefficients between two data sets of all the stations are strong and positive. The t test shows that the difference between means of two data sets is not statistically significant at 95 % confidence. The scores of probability of detection (POD) are strong and false alarm rate (FAR) is appreciably low almost for all the stations. It has been observed from the error structure analysis that usability of the rainfall data from AWS in day to day forecasting of all the stations over Bihar region are more than 75 % for all the stations. The rainfall values obtained from automatic weather observing system (AWOS) are generally lesser than the traditional (conventional) surface observation system. It can be argued that the generally lower rainfall recordings by the automatic rain gauges is due to the greater installation heights (than for traditional, manual standard rain gauges) that results into systematic errors subject to wind field distortions along the gauge orifice. Such types of comparisons are very important for data quality control and standardization of data (Chivla *et al.*, 2002, 2005; WMO, 2001). Since the Automatic gauge uses the tipping bucket mechanism, and the rainfall in the tropics is mostly of showery type, there is also the possibility of overflow of the water collected due to the delay of the tipping hence a lower recording than actual.

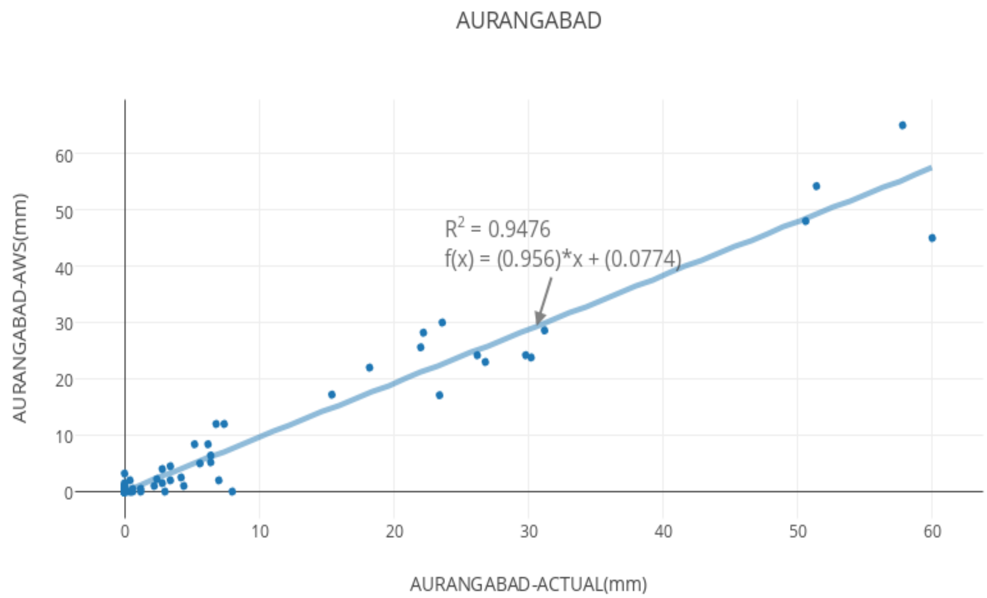
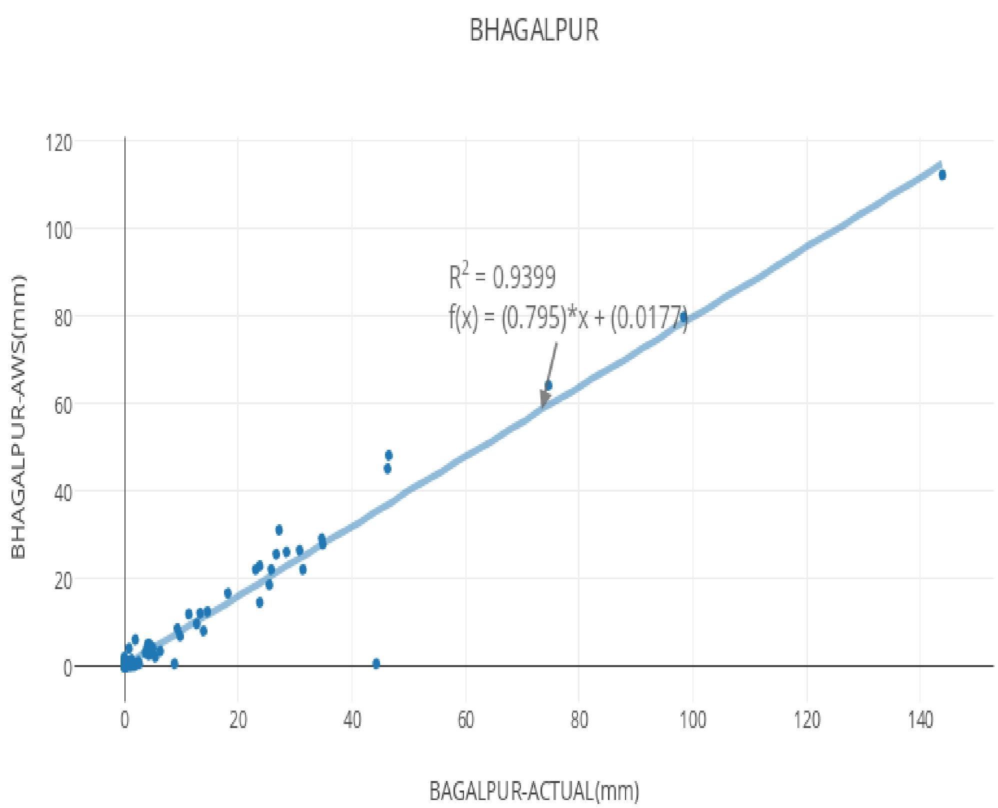


Figure 1 (a)



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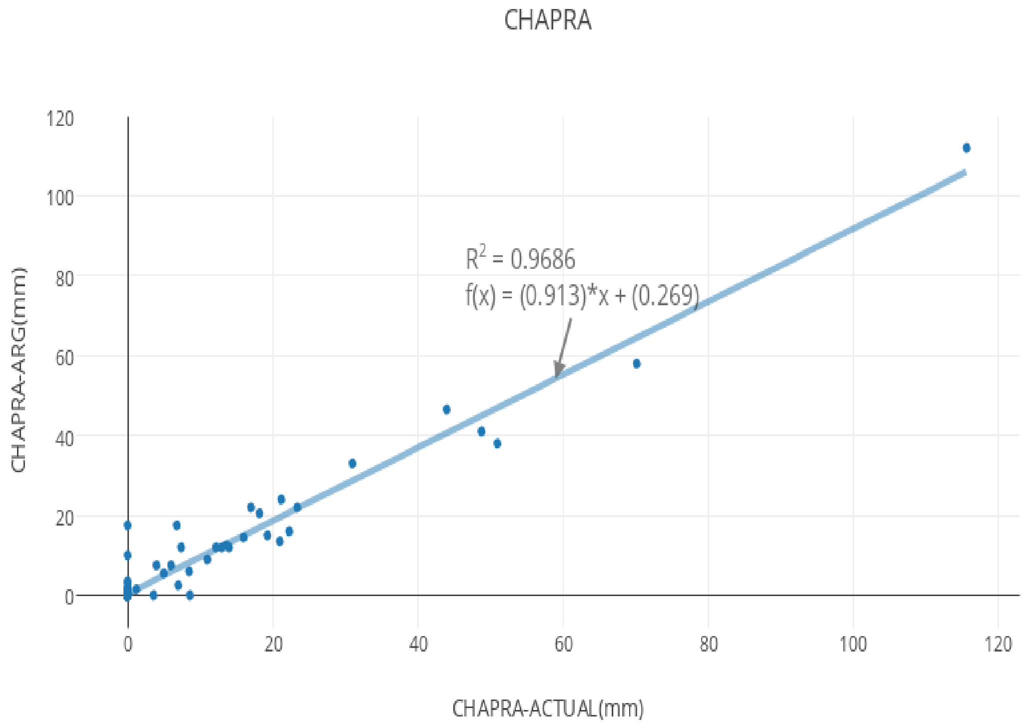

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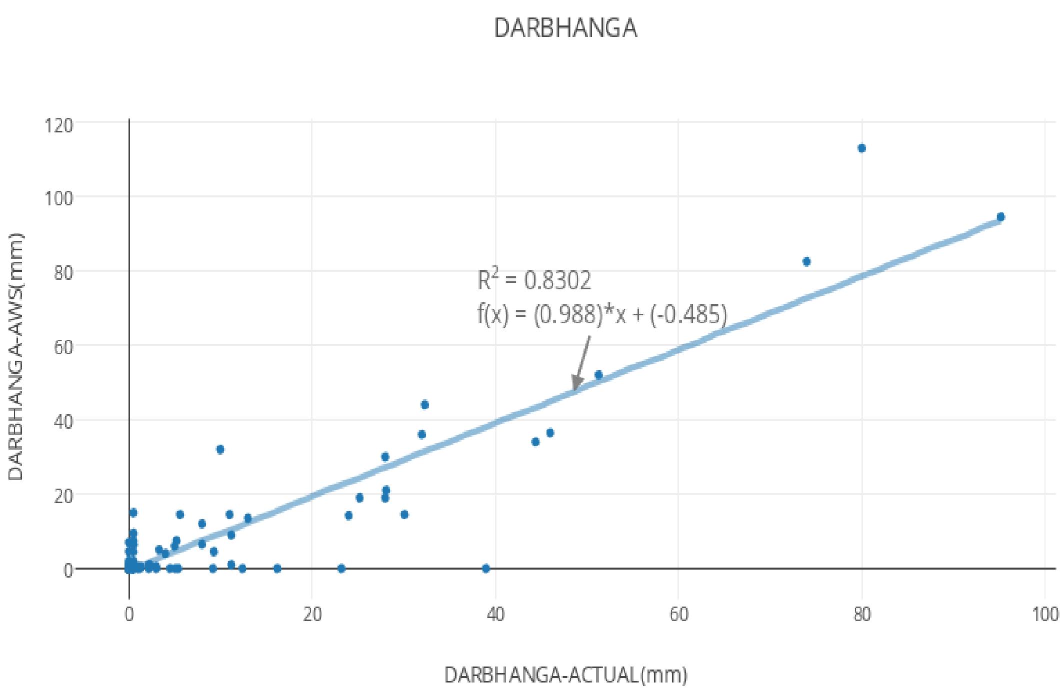

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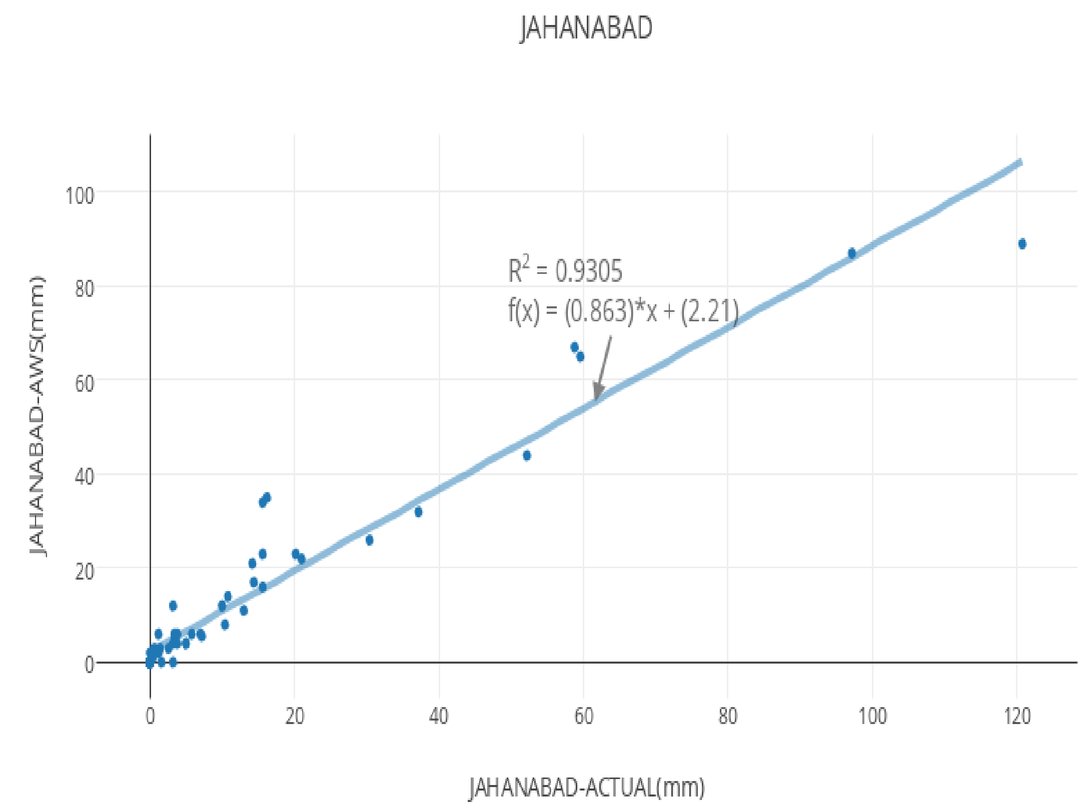

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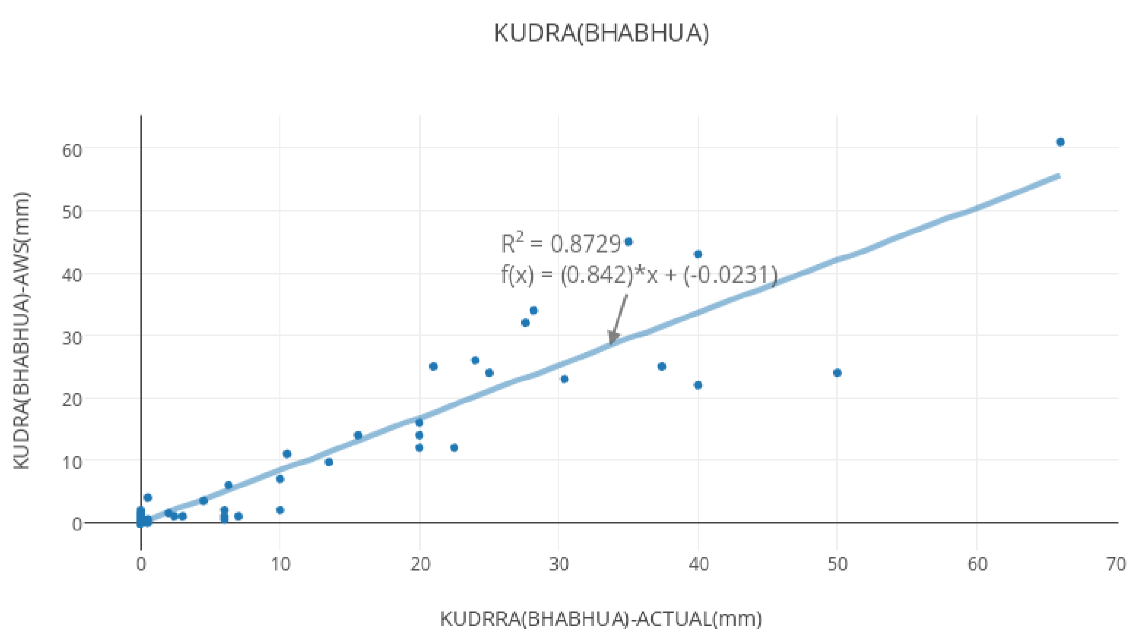

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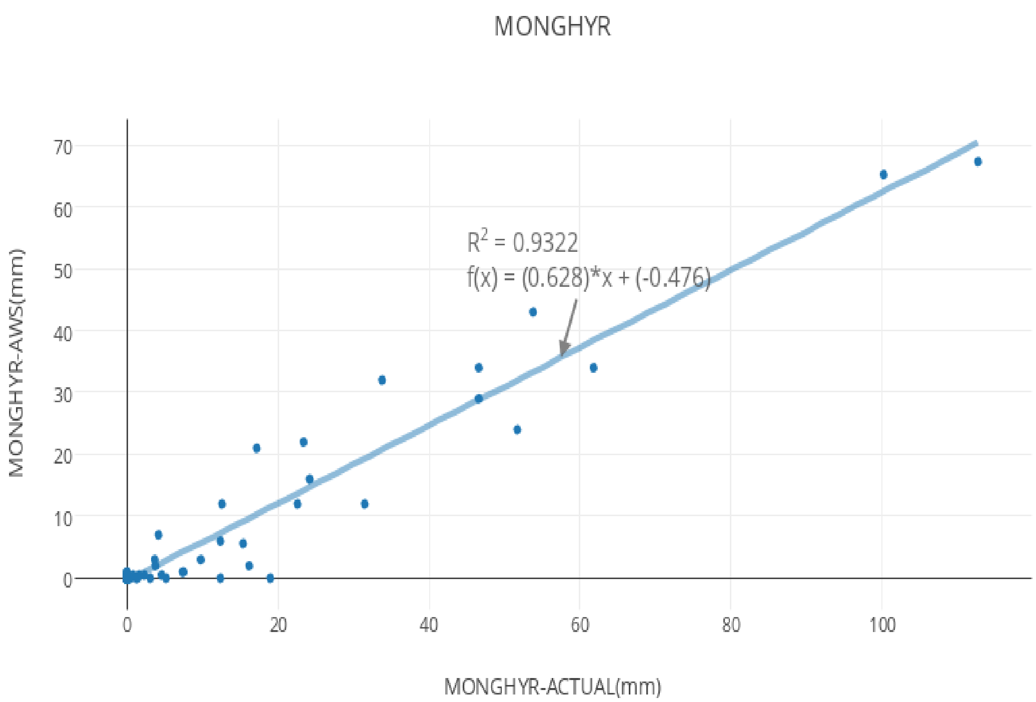

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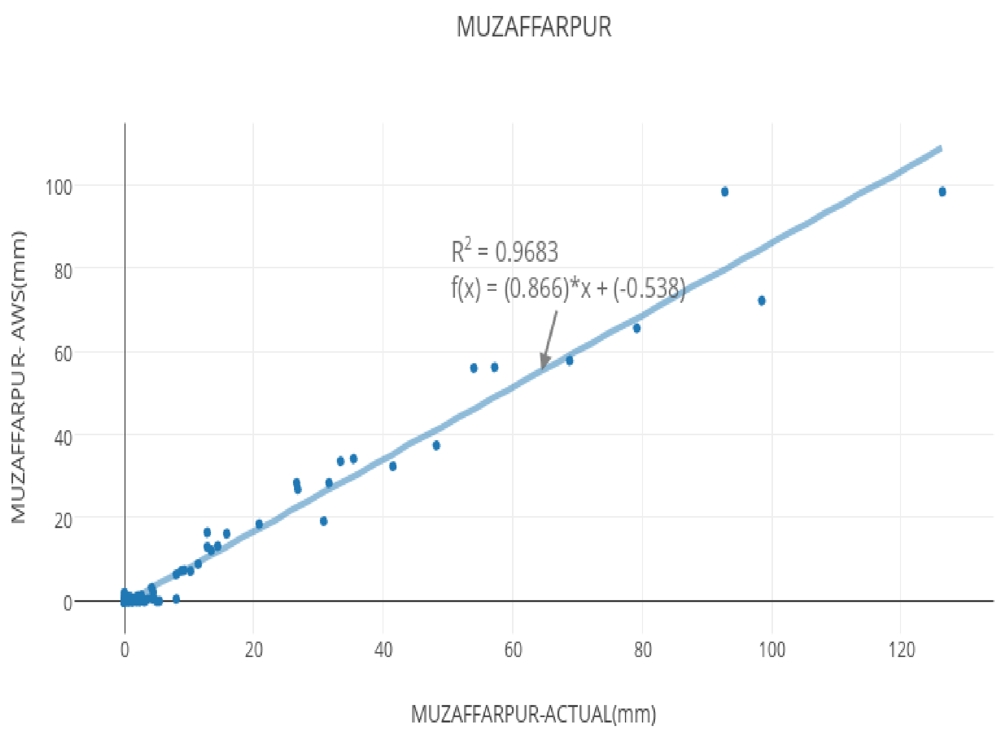

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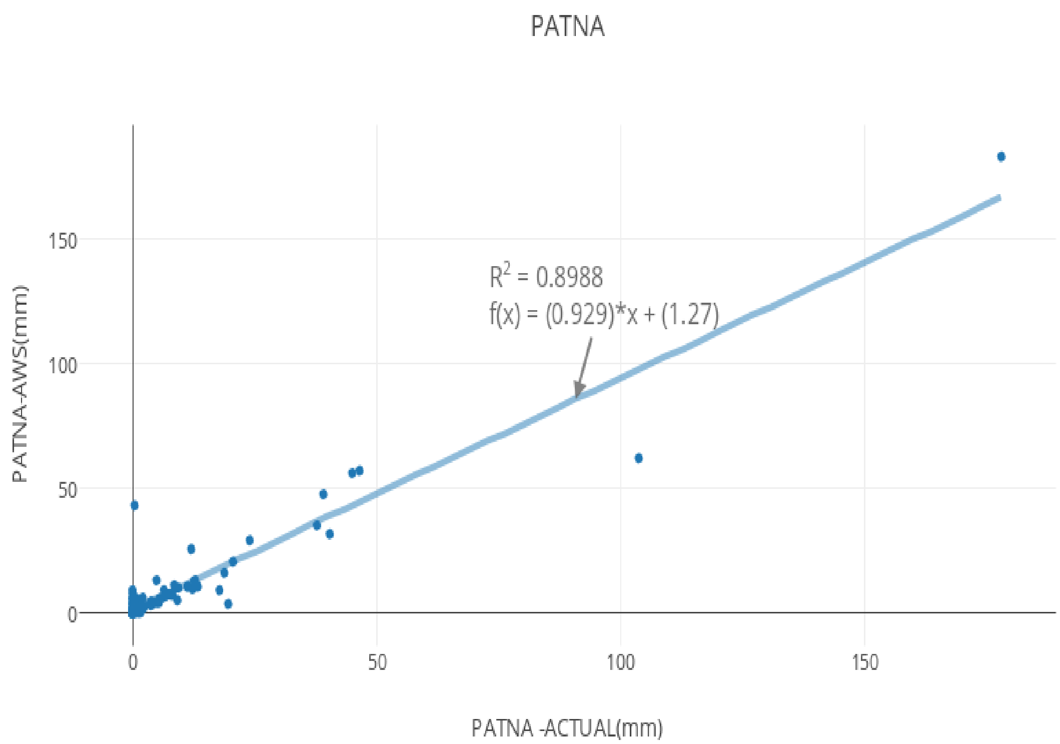
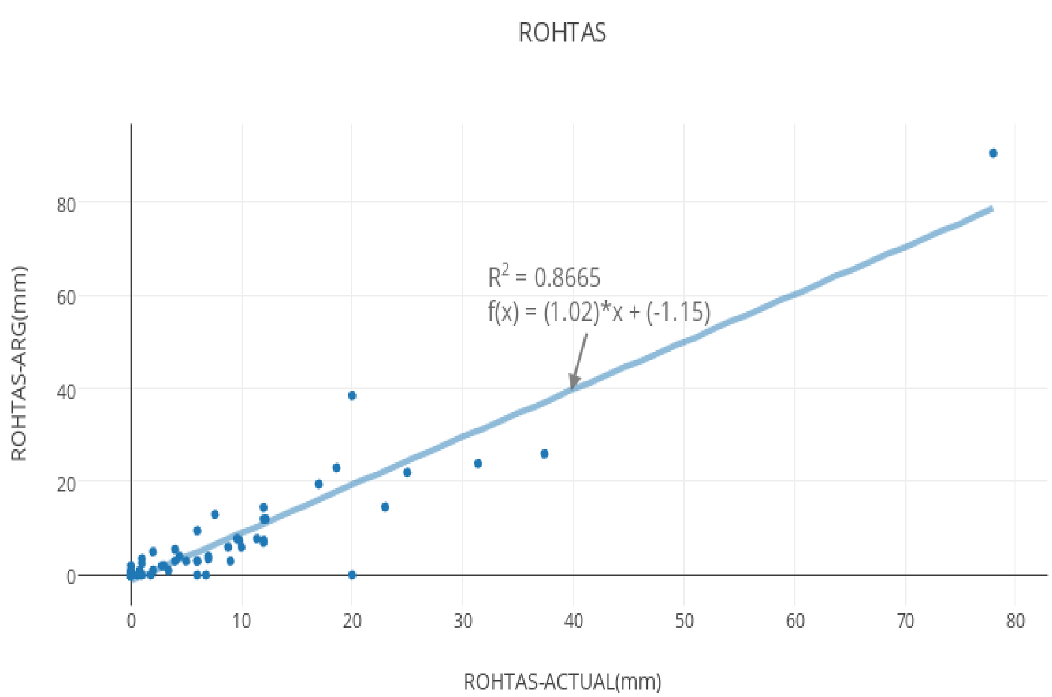


Figure 1 (i)



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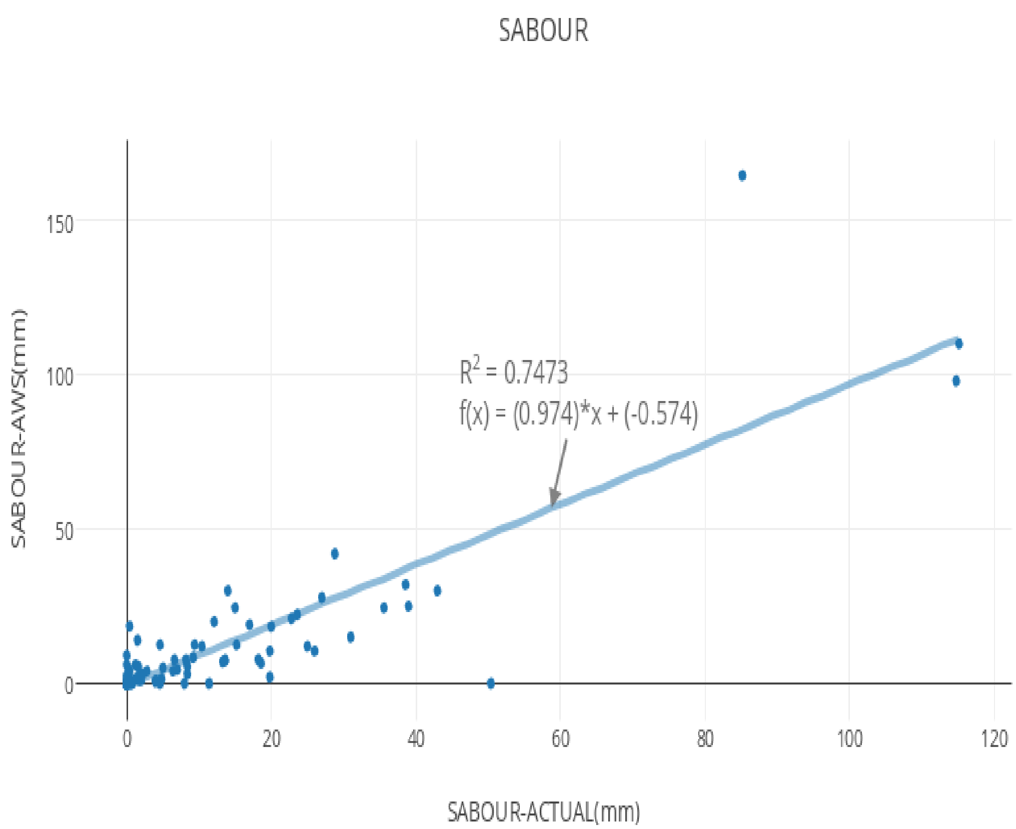

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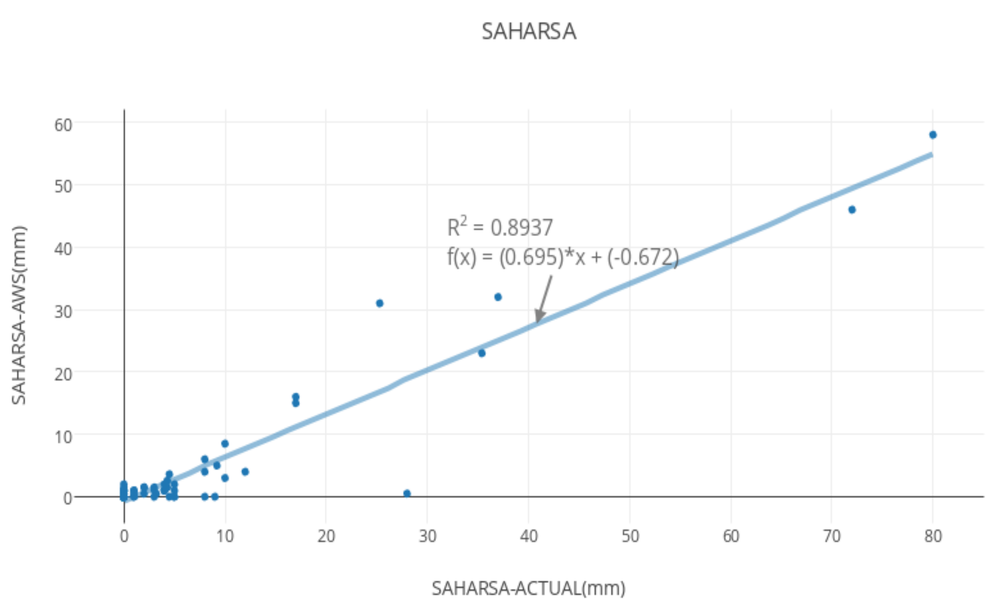

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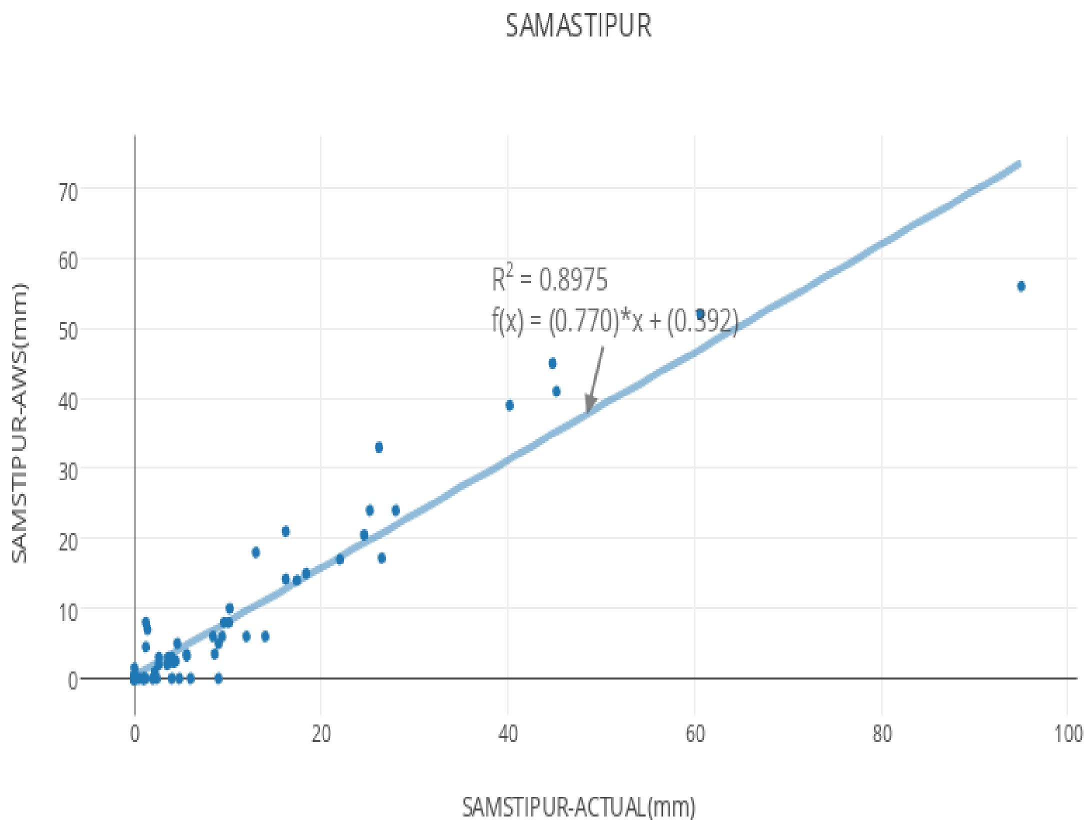

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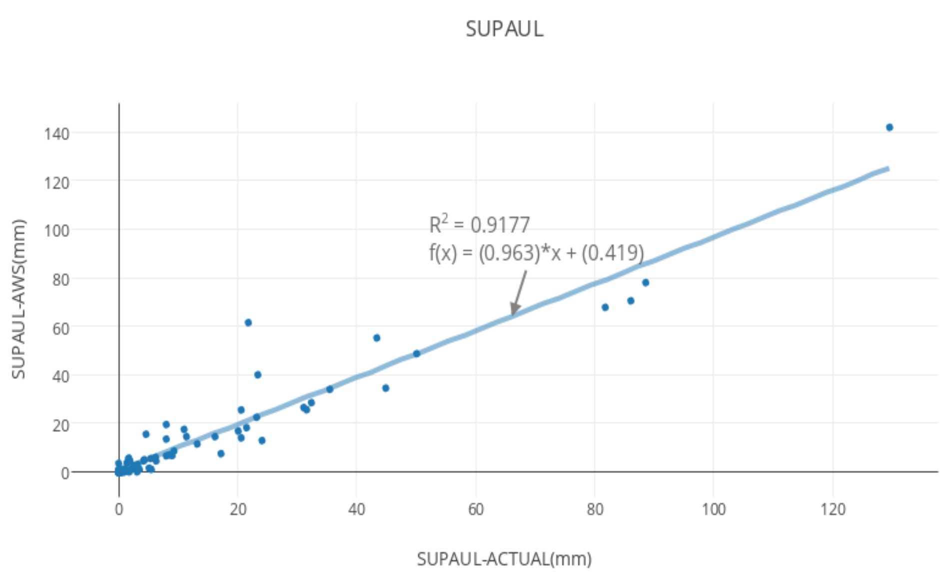

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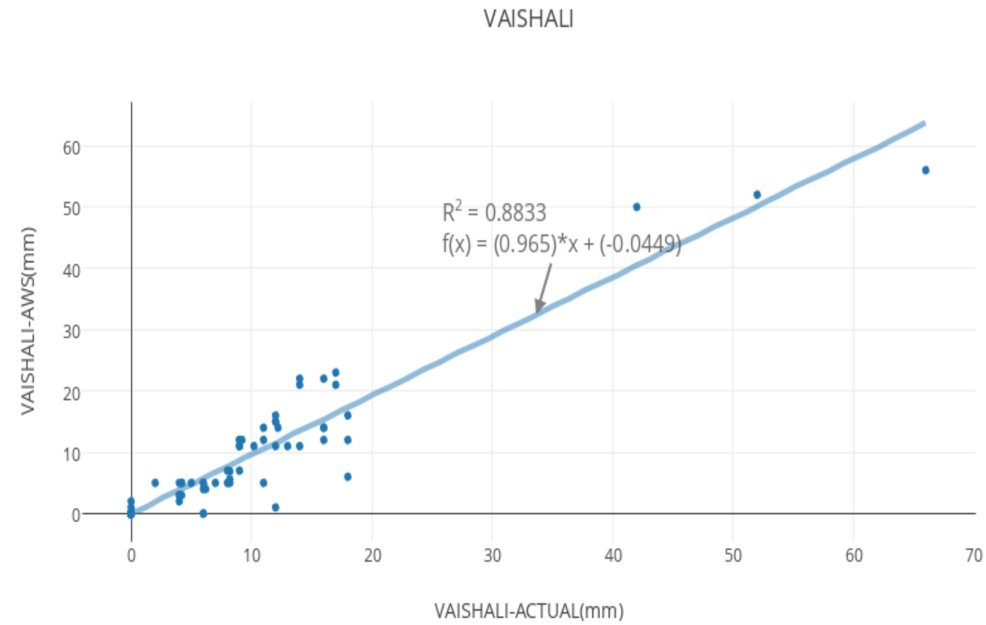

Figure 1 (o)

Figures 1 (a-o): Scatter diagram between AWS /ARG rainfall (mm) and actual rainfall (mm) over Bihar region: Same for Aurangabad (b) For Bhagalpur (c) For Chapra (d) For Darbhanga (e) For Jahanabad (f) Kudra (Bhabhua) (g) For Monghyr (h) For Muzaffarpur (i) For Patna (j) For Rohtas (k) For Sabour (l) For Sahrsa (m) For Samastipur (n) For Supaul (o) For Vaishali

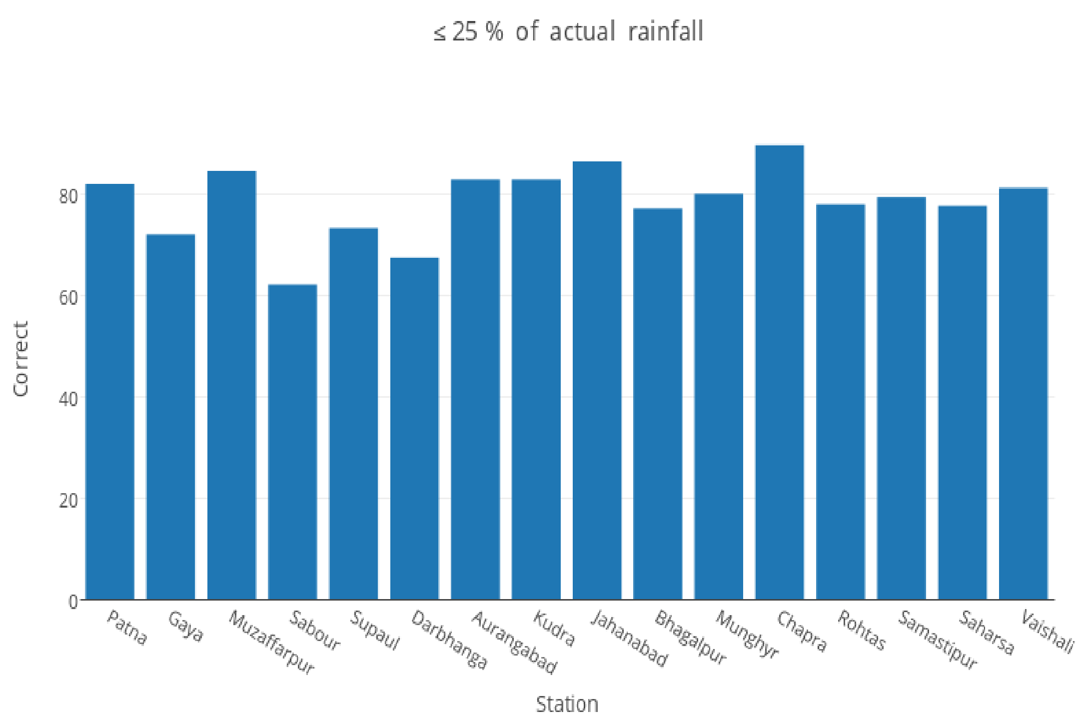

Figure 2 (a): Rainfall percentage of correct values range (≤25 % of actual rain)

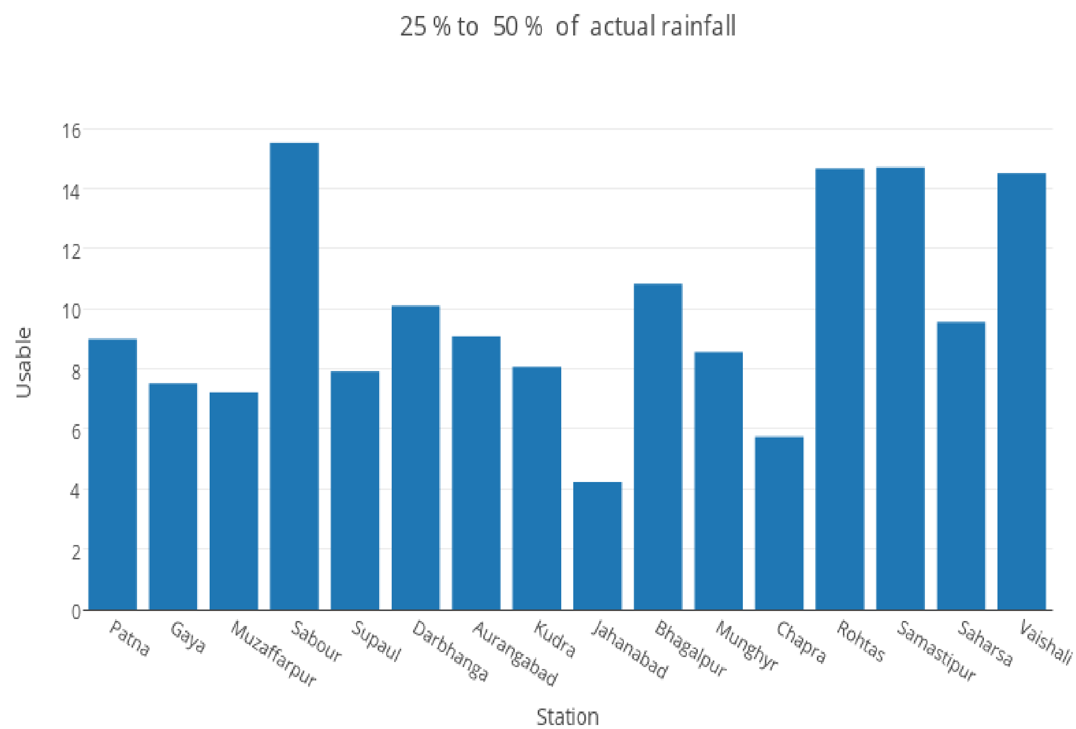

Figure 2 (b): Rainfall percentage of usable values range (25 % to 50 % of actual rain)

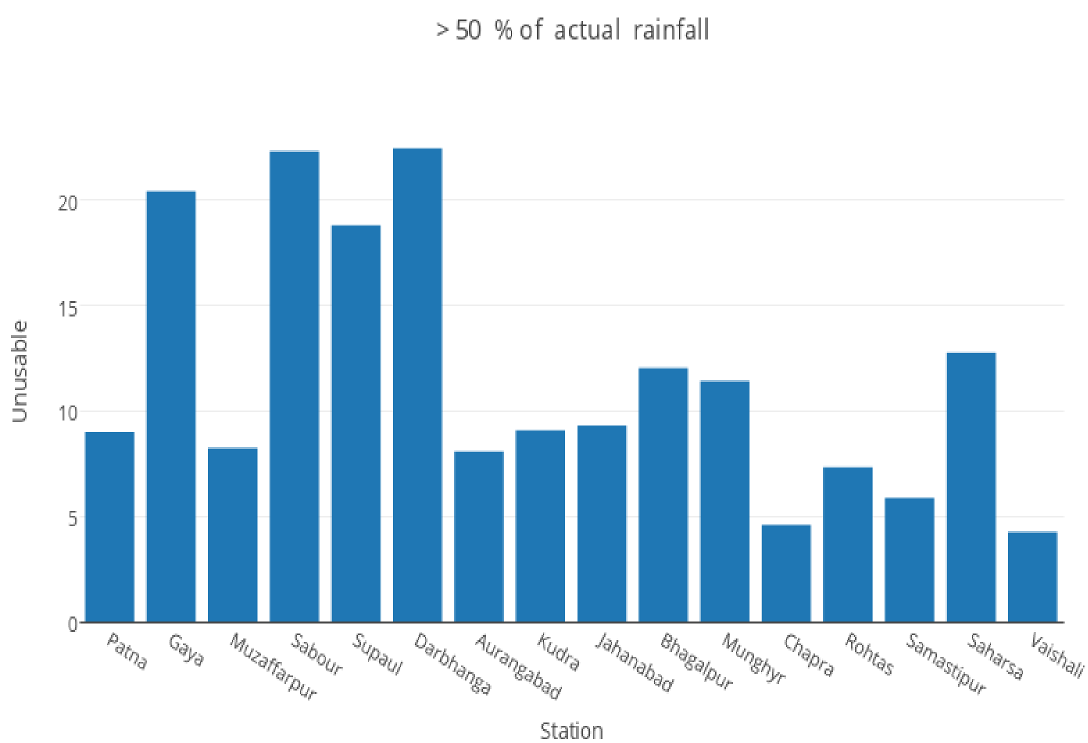

Figure 2 (c): Rainfall percentage of usable values range (> 50 % of actual rain)

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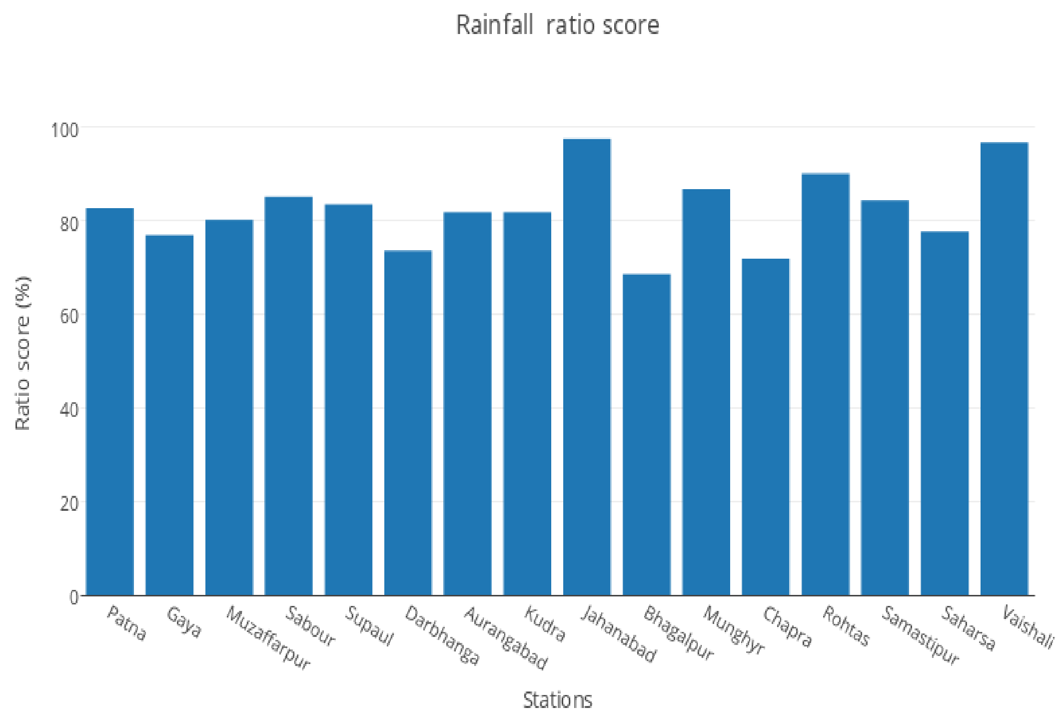

Figure 2 (d): Rainfall ratio score (%)

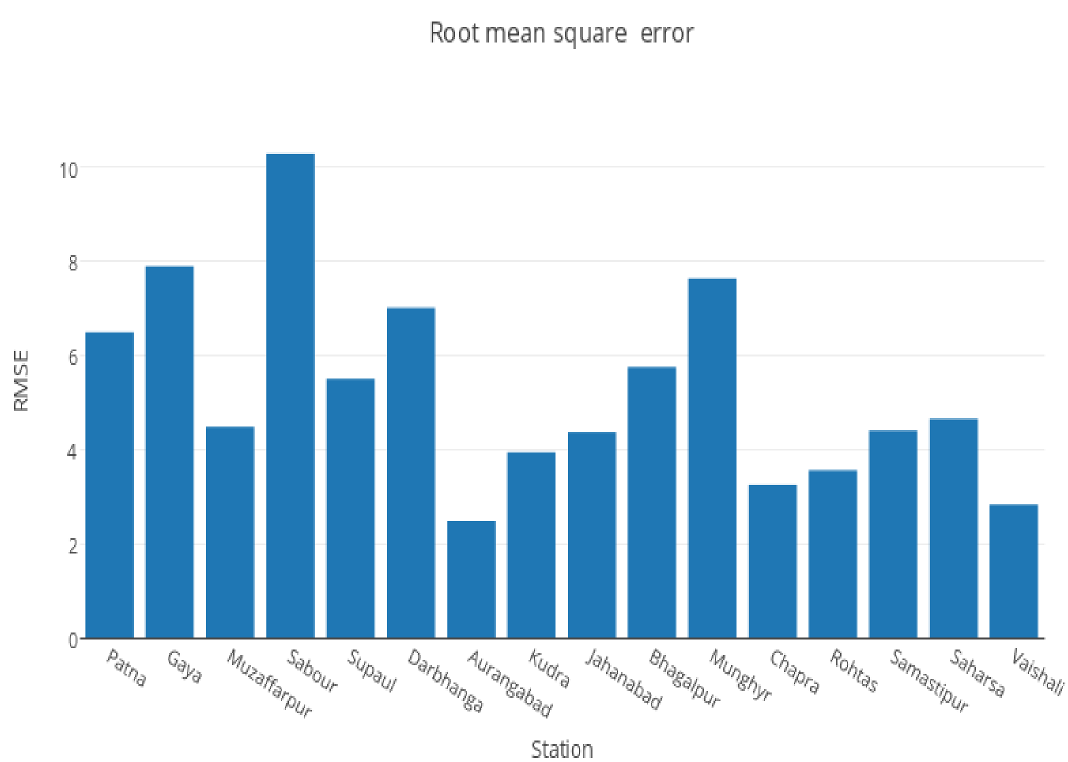

Figure 2 (e): Root mean square error (mm)

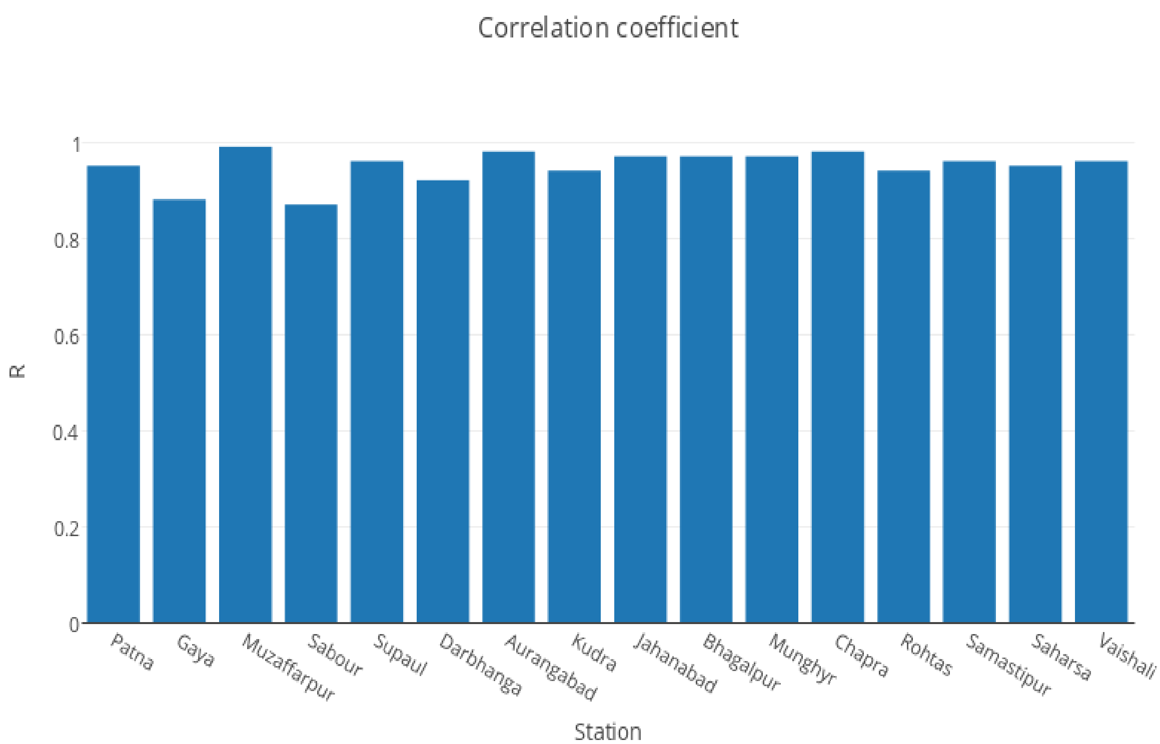

Figure 2 (f): Correlation Coefficient

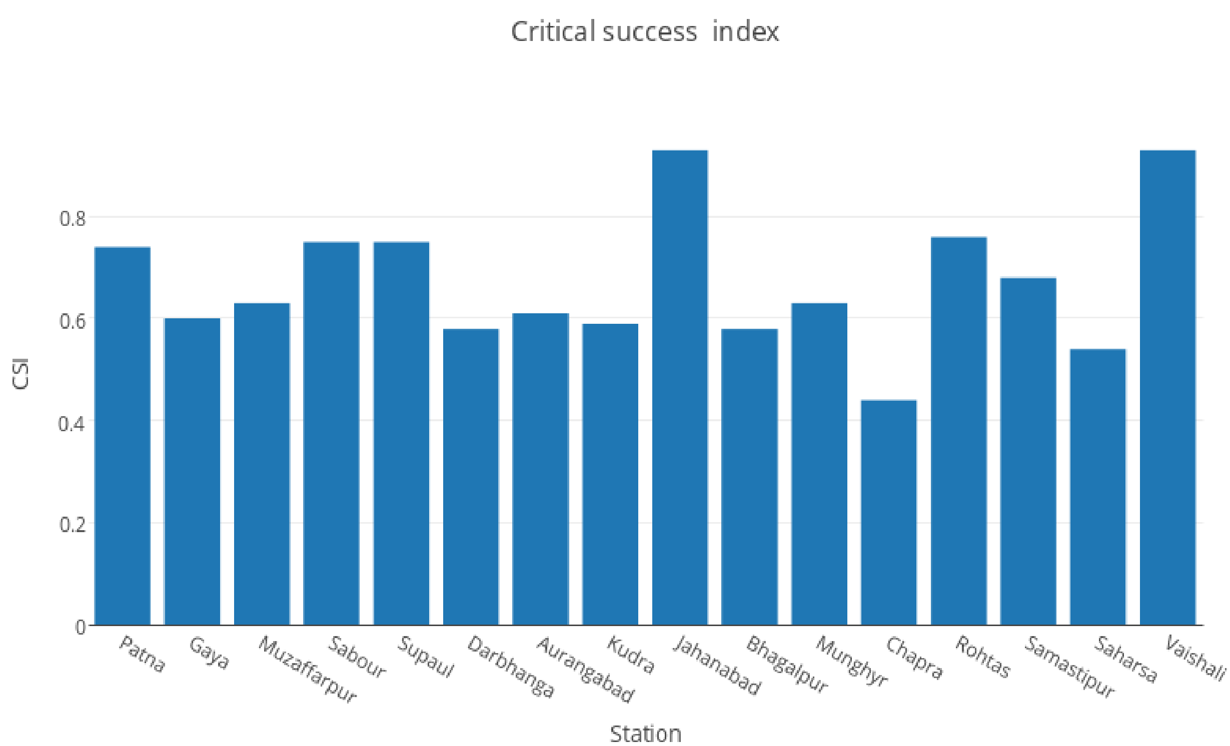

Figure 2 (g): Critical Success Index (CSI)

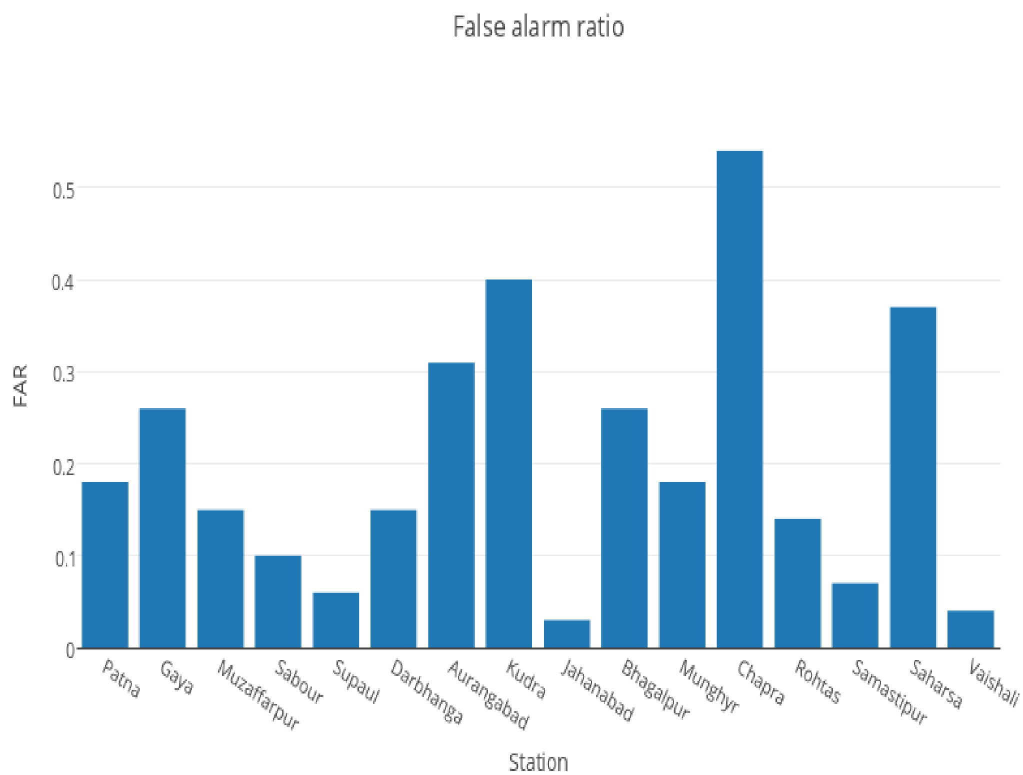

Figure 2 (h): False alarm ratio (FAR)

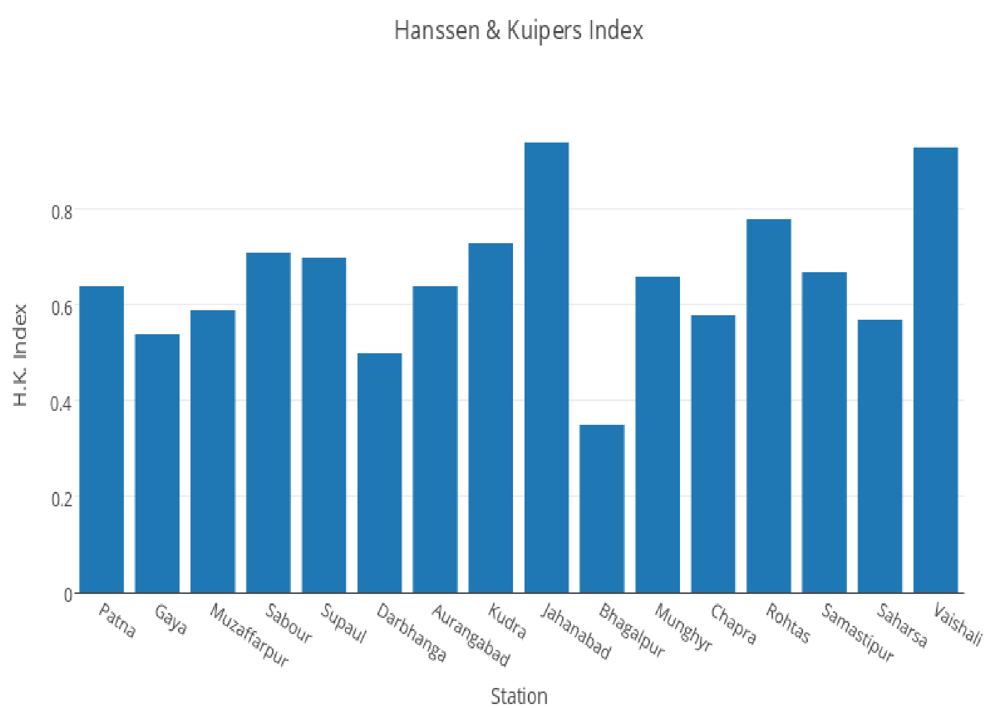

Figure 2 (i): Hanssen & Kuipers Index (HKI)

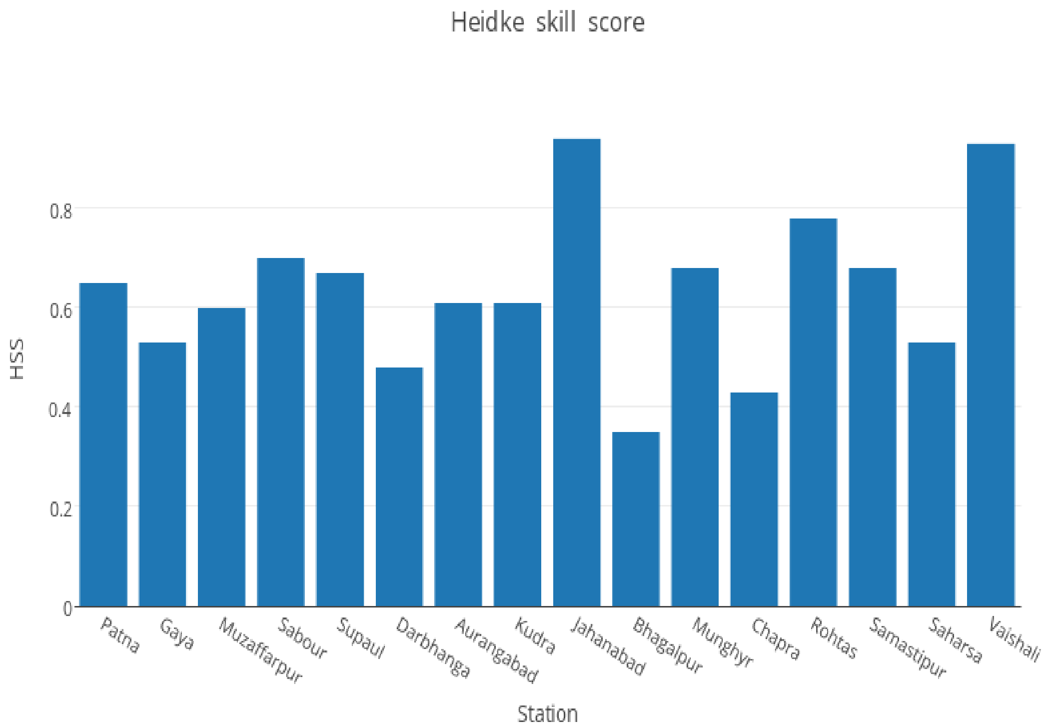

Figure 2 (j): Heidke skill score (HSS)

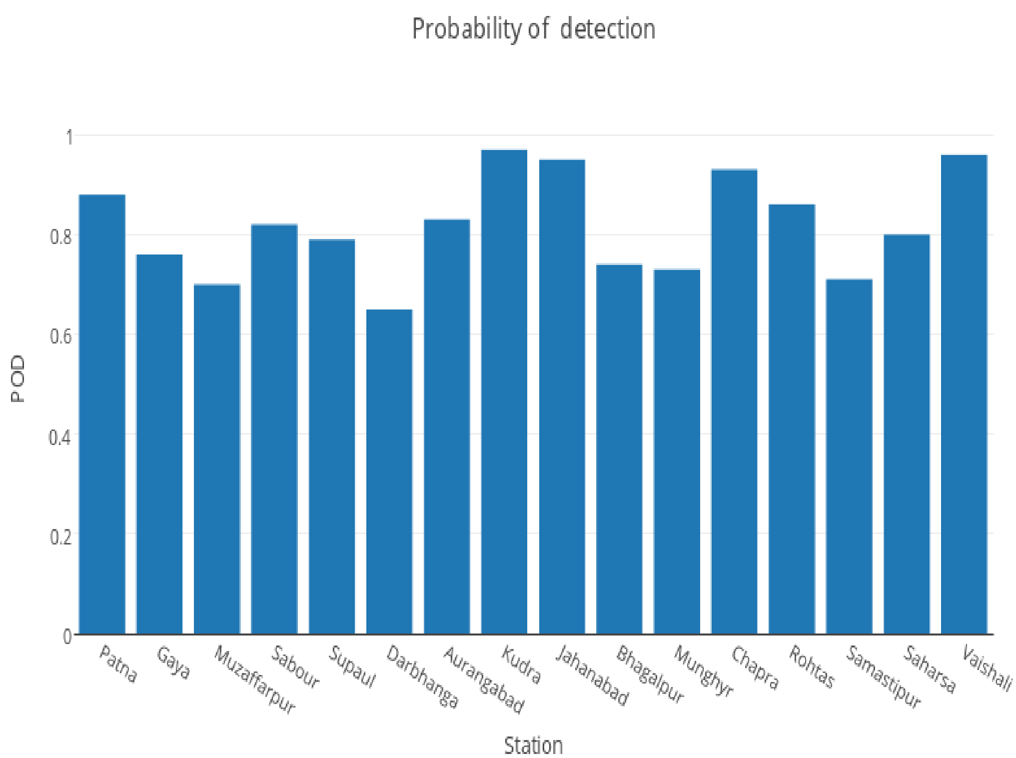

Figure 2 (k): Probability of detection (POD)

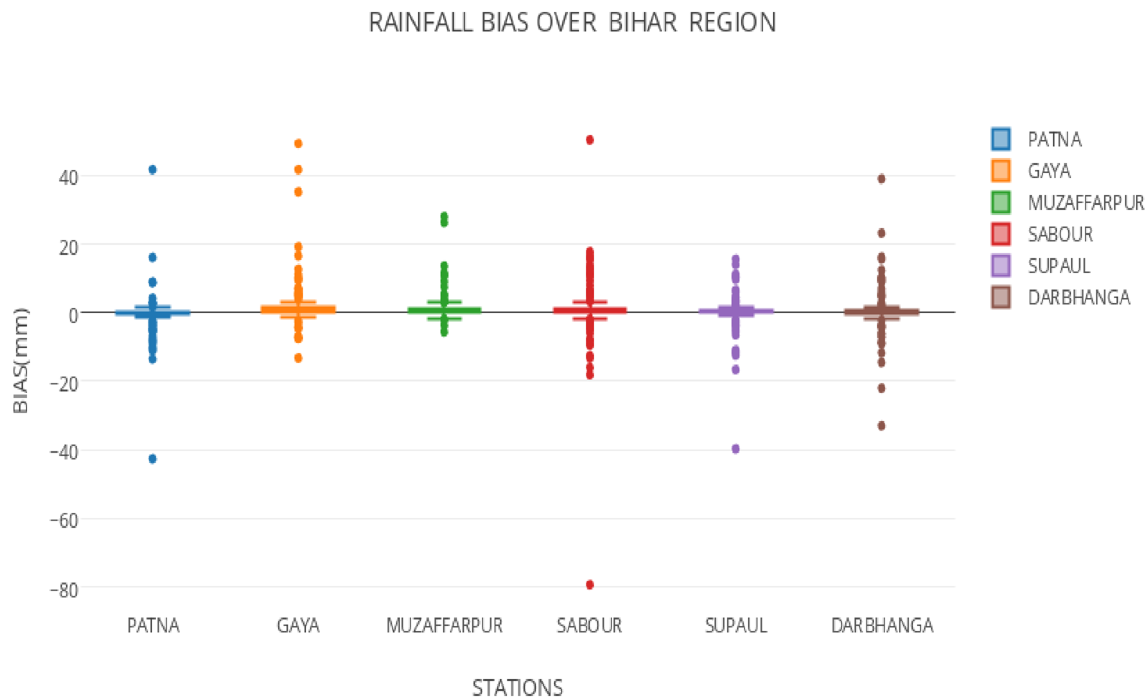

Figure 3 (a): Rainfall biases (mm)

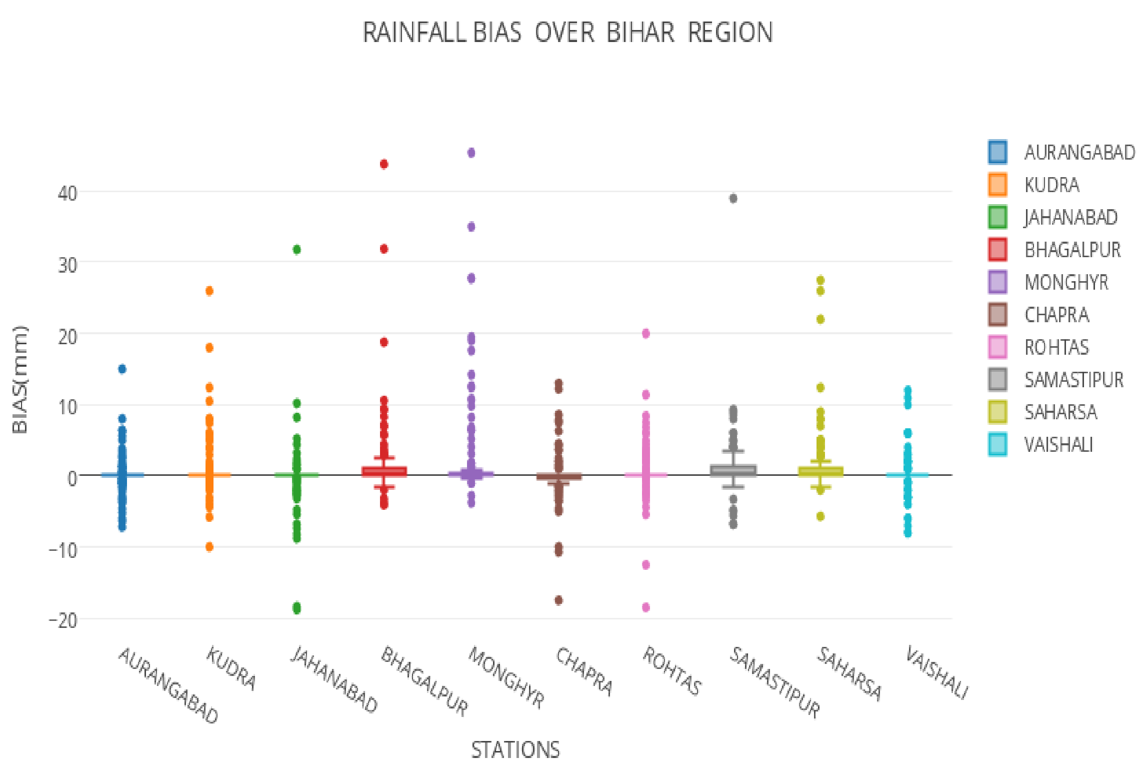

Figure 3 (b): Rainfall biases (mm)

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Figure 4: Districts of Bihar with different agro-climatic zones

Table 1 (a): Hydromet stations (Bihar region) feasibility analysis

Name	**Lat(deg/m)**	**Long (deg/m)**	**District**	**AWS/ARG (IMD) distance (km)**		**State-AWS Distance (km)**	
Araria	26.8	87.23	Araria	**26**	**21**	25	
Forbesganj	26.3	87.25	Araria	**1**	**28**	29	
Arwal	25.24	84.67	Arwal	**1**	**19**	27	
Kinjar	25.21	84.83	Arwal	**17**	**10**	14	
Kurtha			Arwal			--	
Aurangabad	24.75	84.37	Aurangabad			1	32
Daudnagar	25.05	84.24	Aurangabad			35	18
Deo	24.39	84.25	Aurangabad			42	73
Palmerganj	24.54	84.18	Aurangabad			30	60
Rafiganj	24.48	84.38	Aurangabad			30	61
Banka	24.53	86.55	Banka	30		43	
Katoria	24.88	86.91	Banka	49		17	
Cheria B.Pur	25.93	86.09	Begusarai	67		55	
Kodavanpur	25.4	86	Begusarai	38		14	
Sahebpur Kanal	25.47	86.46	Begusarai	12		33	
Bhabhua	25.03	83.37	Bhabhua	2		24	59
Kurda	25.05	83.62	Bhabhua	26		1	17
mohania	25.1	83.36	Bhabhua	9		26	65
Bhagalpur	25.15	87	Bhagalpur	3	**28**	42	11
Bihpur	25.38	87.05	Bhagalpur	27	**24**	98	26
Colgaon	25.16	87.17	Bhagalpur	14	**14**	102	

Sabour	25.23	87.04	Bhagalpur	10		**21**		96	8
Barhara	25.68	84.73	Bhagalpur	52				16	
Kolilwar	25.56	84.08	Bhojpur	40				56	
Buxar	25.34	84.01	Bhojpur	43				29	
Darbhanga	26.1	85.57	Darbhanga	19	**34**		**59**	37	70
Hayghat	26.02	85.87	Dharbhanga	4	**10**		**35**	10	59
Jaley	26.38	85.72	Dharbhanga	32	**36**		**47**	22	73
Kamtaul	26.33	85.82	Dharbhanga	39	**27**		**35**	25	62
Ahirwalia	26.23	85.02	Dharbhanga	**50**				46	
Kessariah	26.35	84.88	E-Champaran	**62**				31	70
Lalbegiaghat	26.4	85	E-Champaran	**50**				28	66
Mahed/Mehshi	26.35	85.1	E-Champaran	**40**				37	75
Motihari	26.4	85.14	E-Champaran	**36**				36	71
Patahi	26.05	85.2	E-Champaran	**46**				71	109
Bodhgaya	24.41	85.02	E-Champaran	8		**62**			
Gaya-aerodrome	24.49	85.01	Gaya	2		**53**		33	24
Sherghati	24.33	84.48	Gaya	57		**93**		73	40
Tekari	24.55	84.05	Gaya	98	1		**4**	100	75
Bhore Borch	26.45	84.11	Gaya	16		**22**		33	
Gopalganj	26.28	84.26	Gopalganj	8		**10**		27	
Hathwa	26.22	84.19	Gopalganj	14		**20**		36	
Jahanabad	25.13	85	Jahanabad	7				2	
Makdumpur	25.09	84.53	Jahanabad	55				48	
Garhi	25.05	86	Jahanabad	54				38	68
Jamui	24.56	86.18	Jamui	3				24	21
Jhajha	25.32	85.47	Jamui	101				91	120
Sono	24.4	86.15	Jamui	21				42	29
Katihar North	25.3	87.4	Jamui	6				23	23
Kursela	25.3	87.18	Katihar	16				40	45
Manihari	25.2	87.37	Katihar	14				34	26
Baltara	25.3	86.5	Katihar					24	
Gogri	25.28	86.38	Khagaria					27	
Khagaria	25.35	86.25	Khagaria					28	
Parbatta	25.15	86.4	Khagaria					40	
Bahadurganj	26.78	87.82	Khagaria					78	
Chagharia	26.17	87.47	Kishanganj					48	
Galgalia	26.16	87.15	Kishanganj					79	
Kishanganj	26.42	88.08	Kishanganj					39	
Taibpur	26.22	88.1	Kishanganj					22	
Thakurganj	26.25	88.05	Kishanganj					21	
Barhia	25.29	86.02	Kishanganj	**15**		**1**		34	
Lakhisarai	25.18	86.1	Lakhisarai	**0**		**14**		24	
Suryagadha	25.37	86.49	Lakhisarai	**45**		**48**		65	
Madhepura	25.55	86.87	Lakhisarai	39		**49**		40	
Murliganj	25.54	87	Madhepura	52		**38**		43	
Udai Kishanganj	26.42	86.58	Madhepura	73					
Balan	26.37	86.2	Madhepura	72	**30**		**11**	18	16
Jainnagar	26.59	86.27	Madhubani	69	**39**		**16**	83	17
Jhanuharpur	26.16	86.4	Madhubani	91	**59**		**35**	26	41
Madhwapur	26.3	85.5	Madhubani	5	**44**		**78**	66	67

Phulparas	26.25	86.4	Madhubani	91	**54**	**26**	25	78
Saulighat	26.25	85.5	Madhubani	1	**46**	**80**	65	69
Monghyr	25.23	86.3	Monghyr	1	**27**		34	
Benibad	26.05	85.35	Muzaffarpur	27			10	
Minapur	26.15	85.2	Muzaffarpur	20			25	
Mushari	25.55	85.3	Muzaffarpur	56			62	
Muzaffarpur	26.07	85.24	Muzaffarpur	11			20	
Rewaghat	25.29	85.32	Muzaffarpur	84			90	
Sahebganj	26.18	84.56	Muzaffarpur	55			88	
Saraiya	26.1	85.15	Muzaffarpur	12			29	
Biharsharif	25.24	85.55	Nalanda	54			17	
Ekangarsarai	25.13	84.14	Nalanda	96			31	
Islampur	25.09	85.13	Nalanda	23			32	
Hisua	24.39	85.3	Nawada	15			41	
Nawada	24.88	85.53	Nawada	45	**27**		21	
Rajauli	24.63	85.5	Nawada	**2**			8	
Barh	25.29	85.43	Patna	39	**14**		60	41
Bihita	25.33	84.52	Patna	33	**99**		143	51
Bikram	25.87	84.52	Patna	54	**99**		145	52
Patna	25.36	85.06	Patna	0	**35**		90	3
Sripalpur	25.27	85.02	Patna	10	**50**		97	9
Dhengraghat	25.52	87.47	Purnea				28	
Purnea	25.46	87.2	Purnea				42	
Chenari	24.55	83.48	Rohtas	53			78	
Dehri	24.55	84.11	Rohtas	11			58	
Indrapuri	24.55	84.07	Rohtas	7			57	
Bihpur	25.38	87.05	Saharsa	70			62	
Simri-Bhaktiyarpur	25.72	86.6	Saharsa	32			3	
Hasanpur	25.41	86.13	Samastipur	74	**61**	**39**	35	
Morwa Tajpur	25.51	85.41	Samastipur	9	**55**	**68**	55	
Pursa	25.55	85.5	Samastipur	11	**46**	**58**	46	
Rosera	25.45	86.02	Samastipur	64	**52**	**23**	91	
Samstipur	25.52	85.48	Samastipur	11	**50**	**61**	49	
Chapra	25.78	84.75	Saran	**1**			20	
Jalalpur	25.5	84.1	Saran	**72**			90	
Marhaura	26.38	84.87	Saran	**67**			68	
Masrakh	26.1	84.8	Saran	**35**			40	
Parsa	26.06	84.16	Saran	**65**			85	
Barbigha	25.15	85.42	Sheikhpura	15				
Sheikhpura	25.09	85.53	Sheikhpura	6				
Sheohar	26.51	85.3	Sheohar	34			241	
Bairgania	26.45	85.17	Sitamarhi	29	**65**	**59**	36	52
Belsand	26.26	85.24	Sitamarhi	20	**40**	**72**	43	50
Dhengbridge	26.43	85.19	Sitamarhi	26	**34**	**56**	35	50
Sonabarsa	26.25	85.36	Sitamarhi	11	**35**	**69**	38	40
Sursand	26.39	85.43	Sitamarhi	7	**17**	**52**	20	27
Darauli	26.05	84.08	Siwan	16	**1**	**22**	51	
Hussainganj	26.14	84.34	Siwan	13	**26**	**7**	23	
Maharajganj	26.12	84.8	Siwan	59	**10**	**51**	27	

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Pachrukhi	26.05	84.25	Siwan	10	**45**	**7**	35	
Siswan	25.57	84.24	Siwan	**75**		**59**	79	
Basua	26.07	86.36	Supaul	**24**				
Bhimnagar	26.25	86.55	Supaul	**17**				
Birpur	26.25	87	Supaul	**43**				
Nirmali	26.2	86.4	Supaul	**23**				
Supaul	26.08	86.35	Supaul	**25**				
Tribeni Ganj	26.07	86.54	Supaul	**7**				
Goraul	25	85.36	Vaishali	54			10	
Janhdaha	25.72	84.65	Vaishali	58			97	
Mahua	24.48	85.24	Vaishali	98			66	
Vaishali	25.52	85.1	Vaishali	10			54	
Bagha	27.1	84.09	W-Champaran	76			54	101
Chanpatia	26.57	84.31	W-Champaran	15			33	47
Gaunaha	27.21	84.31	W-Champaran	82			50	115
Ramnagar	27.1	84.19	W-Champaran	73			47	101
Tribeni/Balmiki	27.25	83.55	W-Champaran	48			108	130

Table 1 (b): Collocation details of AWS /ARG in Bihar region

S.No	Stations	District	Lat	Long	Remarks
1	Aurangabad	Aurangabad	24.75	84.37	01 km (state)
2	Bhagalpur	Bhagalpur	25.15	87	03 km
3	Chapra	Saran	25.78	84.75	01 km
4	Darbhanga (Hayghat)	Darbhanga	26.02	85.87	04 km
5	Jahanabad	Jahanabad	25.13	85	02 km (state)
6	Kudra	Bhabhua	25.05	83.62	01 (state)
7	Monghyr	Monghyr	25.23	86.3	01 km
8	Muzaffarpur	Muzaffarpur	26.07	85.24	11 km
9	Patna	Patna	25.36	85.06	Collocated
10	Rohtas (Indrapuri)	Rohtas	24.55	84.07	07 km
11	Sabour	Bhagalpur	25.23	87.04	08 km
12	Saharsa (Simri-Bhaktiyarpur)	Saharsa	25.72	86.6	03 km (state)
13	Samastipur (Morva Tajpur)	Samastipur	25.51	85.41	09 km
14	Supaul (Tribeni Ganj)	Supaul	26.07	86.54	07 km
15	Vaishali	Vaishali	25.52	85.1	10 km

Table 2: Rainfall statistics (Actual and AWS /ARG data):

Statistical Score	**Meteorological Station**							
	Patna	**Gaya**	**Muzaffarpur**	**Sabour**	**Supaul**	**Darbhanga**	**Aurangabad**	**Kudra**
R.S	82.64	76.86	80.17	85.12	83.47	73.55	81.82	81.82
H.K	0.64	0.54	0.59	0.71	0.7	0.5	0.64	0.73
POD	0.88	0.76	0.7	0.82	0.79	0.65	0.83	0.97
FAR	0.18	0.26	0.15	0.1	0.06	0.15	0.31	0.4
CSI	0.74	0.6	0.63	0.75	0.75	0.58	0.61	0.59
HSS	0.65	0.53	0.6	0.7	0.67	0.48	0.61	0.61
RMSE	6.49	7.89	4.48	10.28	5.5	7.01	2.48	3.94
CORRECT	82	72.04	84.54	62.14	73.27	67.42	82.83	82.83
USABLE	9	7.53	7.22	15.53	7.92	10.11	9.09	8.08
UNUSABLE	9	20.43	8.25	22.33	18.81	22.47	8.08	9.09
R	0.95	0.88	0.99	0.87	0.96	0.92	0.98	0.94
Statistical Score	Meteorological Station							
	Jahanabad	Bhagalpur	Monghyr	Chapra	Rohtas	Samastipur	Saharsa	Vaishali
R.S	97.52	68.6	86.78	71.9	90.08	84.3	77.69	96.69
H.K	0.94	0.35	0.66	0.58	0.78	0.67	0.57	0.93
POD	0.95	0.74	0.73	0.93	0.86	0.71	0.8	0.96
FAR	0.03	0.26	0.18	0.54	0.14	0.07	0.37	0.04
CSI	0.93	0.58	0.63	0.44	0.76	0.68	0.54	0.93
HSS	0.94	0.35	0.68	0.43	0.78	0.68	0.53	0.93
RMSE	4.37	5.75	7.63	3.25	3.56	4.4	4.65	2.83
CORRECT	86.44	77.11	80	89.66	77.98	79.41	77.66	81.2
USABLE	4.24	10.84	8.57	5.75	14.68	14.71	9.57	14.53
UNUSABLE	9.32	12.05	11.43	4.6	7.34	5.88	12.77	4.27
R	0.97	0.97	0.97	0.98	0.94	0.96	0.95	0.96

Acronym used: RS = Ratio score of rainfall, H.K = Hanssen & Kuipers Index, POD= Percentage of detection, FAR= False alarm rate, CSI= Critical success Index, HSS=Heidke skill score, RMSE= Root mean square error, R= Correlation of rainfall

Table 3: Rainfall statistical analysis

Stations	**t**	**df**	**SE**	**P**	**Comment**	
1	Patna	0.21	240	2.74	0.814	NSG
2	Gaya	1.01	240	1.96	0.315	NSG
3	Muzaffarpur	0.55	240	2.66	0.583	NSG
4	Sabour	0.24	240	2.55	0.811	NSG
5	Supaul	0.01	240	2.53	0.988	NSG
6	Darbhanga	0.19	240	2.17	0.844	NSG
7	Aurangabad	0.05	240	1.49	0.955	NSG
8	Kudra	0.51	240	1.42	0.610	NSG
9	Jahanabad	0.21	240	2.13	0.832	NSG
10	Bhagalpur	0.67	240	2.28	0.504	NSG
11	Monghyr	1.35	240	1.90	0.177	NSG
12	Rohtas	0.36	240	1.27	0.720	NSG
13	Saharsa	1.09	240	1.27	0.276	NSG
14	Samastipur	0.69	240	1.55	0.488	NSG
15	Vaishali	0.15	240	1.24	0.881	NSG

Concluding Remarks

The comparison analysis of AWS/ARG rainfall with manual (actual) rainfall data from part time or departmental observatories of Bihar region shows that:

1. The rainfall bias between manual (actual) and automatic rainfall data ranges from ±5 mm to ±20 mm.
2. POD values are strong and FAR values are quite low.
3. The usability of the AWS/ARG data in day to day weather analysis is more then 75 % and can be easily utilized in model simulation also.
4. The t test shows that the difference between means of two data sets is not statistically significant at 95 % confidence.
5. The rainfall correlation between the two data sets is very strong.

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