Watch-keeping Mechanism

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Executive Summary

Following the catastrophic floods in Canacona taluka, the Government of Goa constituted the Canacona Flash Floods Study Committee to go into the causes of the event and to suggest remedial measures to enable better preparedness in the future. One of the recommendations made by the committee was to put in place a watch-keeping mechanism, with the India Meteorological Department (IMD) as its nodal centre, for such events in the future.

An examination of the pattern of rainfall during the flood event suggests that the existing network of automatic weather stations (AWSs) needs to be augmented. Sites vulnerable to flooding and damage were identified and some were selected as sites for locating AWSs. The criteria for deciding vulnerability were the following.

1. Valleys surrounded on three sides by hills were considered more vulnerable.

2. If such a valley included a settlement zone with a large population, or included agricultural land, it was considered as a potential disaster zone. The locations in Goa that were vulnerable to flooding were determined using topographical data from the Shuttle Radar Topography Mission (SRTM). Google Earth and Google Maps were used to pinpoint the locations for the AWS.

A total of 14 locations have been identified for new AWS/ARG installations: (1) Valpoi, (2) Sanquelim, (3) Sateri, (4) Chorla, (5) Virdi, (6)) Partagol, (7) Sanguem, (8) Mollem, (9) Tisk, (10) Ponda, (11) Verna, (12) Loutulim, (13) Siolim and (14) Saligao. Of these 14 locations, sites 1–10 are considered as high-priority zones and locations 11–14 are not as vulnerable.

In summary, we propose a watch-keeping mechanism comprising of the following.

1. A Doppler Radar in place to look far, up to a range of 400 km from the base, to forewarn the watch keepers of the approach of any convective system.

2. A network of automatic weather-observing systems, as suggested above, to provide the necessary adequate live input data on rainfall to the flood-risk assessment software.

3. A nodal centre to receive the online input data from the network of weather-observing systems to gauge the impending flood risk at the IMD, Panaji as per the report of the Canacona Flash Floods Study Committee.

4. A dedicated watch-keeping team at IMD, Panaji to observe *round-the-clock* watch, when found necessary. They will start analysing the incoming weather data from the online gauges critically to assess the situation at all the locations simultaneously and to raise a red alert on sensing any likelihood of a disaster.

5. A multifaceted team empowered to take decisions on the spot, to act on the *red alert*.

1 Introduction

1.1 Background

The 2 October 2009 floods brought home in a telling fashion the need for preparedness to face natural disasters. Following the catastrophic floods in Canacona taluka, the Government of Goa constituted the Canacona Flash Floods Study Committee to go into the causes of the event and to suggest remedial measures to enable better preparedness in the future.

Several surveys were made at the affected site by the teams of NIO to collect the basic data. The data were analysed and the committee submitted its findings (CFFSC, 2009) to the Government of Goa. As per the report, the copious rainfall of 271 mm, which occurred within a span of 7 hours, from 0930 hrs. to 1630 hrs. on 2 October 2009, was the direct cause of the disaster. The committee concluded, however, that this rainfall burst was but the trigger for this disaster: the events of the past few months had provided the base on which this trigger could be pulled. The long sequence of events that led to the disaster are the following (CFFSC, 2009):

1. The normal rainfall in Canacona during June to September is 2953 mm. In 2009, the area had a normal monsoon, and 2875 mm of cumulative rainfall. Hence, by the end of September the soil is expected to have been loaded with high moisture.

2. Canacona received 252 mm of rainfall between 0830 hrs. of 29 September and 0830 hrs. of 2 October 2009. This intense rainfall would have saturated the soil and must have flooded the channels to their capacity.

3. The catchment areas of the Talpona and Galgibag rivers are on high lands with steep slopes. They are vulnerable to mudslides and the rivers flow through narrow valleys vulnerable to flooding. The 7-hour long rain event on 2 October had no scope of soaking the soil or percolating because the soil was already saturated. Whatever precipitation fell on the top of the hills cascaded down the slope, causing assorted kinds of damages depending on the terrain through which it passed. It caused mudslides at above 300 m, marooned the arable land in the valleys

below, and deposited the mud and debris which it brought down from the slope, in the river channel. The rate of rainfall was too high for the river to absorb, and the estimated discharge in the river that day was about 10 times the normal peak monsoon discharge.

After analysing all the assembled data, the committee made four specific recommendations in its report.

1. The areas vulnerable to mudslides should be mapped and site-specific disaster plans must be chalked out for the high-vulnerability zones.

2. The areas vulnerable to flooding should be identified and disaster plans must be framed for the high-vulnerability zones.

3. A watch-keeping mechanism must be put in place to look out for impending disaster if a similar rain event occurs in the future. The IMD must form the nerve centre of such a watch.

4. The State of Goa must make IMD's *Cyclone Warning Dissemination System* operational in the state.

The committee noted that such intense-rainfall events are common on the western side of the western ghats during the southwest monsoon, and that such a phenomenon could happen anywhere along the west coast. The 950 mm of rainfall that Mumbai received within 24 hours on 26 July 2005 is a remarkable example. One does not have any control over these kinds of natural intense-rainfall events, but awareness and preparedness can help mitigate the impact of the damage due to these natural disasters.The committee recommended that NIO prepare three reports, one each on items 1–3 above. This report concerns the watch-keeping mechanism.

2 Approach

Live information on the rate of precipitation is one of the basic requirements for identification of the areas with high vulnerability to flooding. The possibility of watch-keeping on a reasonable scale with the existing systems in Goa was considered. Table 1 gives the amount of cumulative rainfall on four days, from 29 September to 2 October 2009, at six locations in South Goa (see Figure 1 for the locations). It may be seen that the daily rainfall was sporadic and there was no pattern or any regularity at the stations in spite of their being geographically so close.

Hence it is inferred that a network of rain gauges of better spatial coverage is necessary, and we need to install a few more Automatic Weather Stations (AWSs) or Automatic Rain Gauges (ARGs) in Goa to assemble a network adequate for such events. As per the weather records of the AWS at Canacona, installed by Indian Space Research Organization (ISRO), an intense shower started at about 0930 hrs. and lasted up to 1430 hrs. on 2 October 2009. Later, when the team from NIO went around at the affected site to assemble the available information, it came to know that the flooding started at about 1130 hrs. Hence, the time available from the time the intense rainfall started to the occurrence of the flood, was just two hours. An implication is that very little time was available for raising an alarm or for any action. The committee noted that it would have been impossible to analyse the event had it not been for the fortuitous presence of the ISRO AWS, which was part of a research programme and did not form part of the normal weather network. That only two hours separated the rainfall burst from the flood makes it obvious that the conventional cumulative rain gauges will not serve the purpose of disaster warning as they will give the cumulative daily rainfall from 0830 hrs. of a day to 0830 hrs. of the next day.

Considering the present scenario, it is suggested that the existing weather observing facilities be augmented monitor the weather conditions on a reasonably fine scale and warn the administrative system of any impending disaster. The Canacona floods imply the need for more automatic weather-observing systems that are connected to an office serving as the nodal centre. The data must be available online at this office, which, in turn must keep a vigil on a round-the-clock basis whenever required, and initiate action on sensing any trouble brewing. We need to follow a certain logic while placing these additional weather observing systems.

1. There should not be any duplication of data due to installation of sensors from the same or different organizations at the same location,

2. These systems should provide adequate live data for foreseeing the conditions to raise a red alert.

3. The installation area must be stable, safe, and fairly easily accessible for routine maintenance purposes.

3 Existing weather-observing systems in Goa

Before getting into the process of identifying new sites for the AWSs, we take stock of all the meteorological observation systems existing in Goa. The IMD and ISRO are operating their weather observing systems in Goa at present.

3.1 India Meteorological Department

IMD has its regional office of Goa functioning from Altinho, Panaji. Their observation schedule is as follows.

1. Surface meteorological parameters, viz., atmospheric temperature, relative humidity, atmospheric pressure, wind speed and direction, solar radiation, are recorded at synoptic hours: at every three hours starting from 00 UTC (00 UTC, 03 UTC, 06 UTC, and so on). The data is passed on to the Head Office at Delhi to add to the national grid for analysis.

2. Balloon ascents are done twice a day at 00 UTC and 12 UTC to get the data on variation of atmospheric temperature, relative humidity and wind velocity in vertical direction.

3. At 10 various outposts in Goa, daily cumulative rainfall data is collected and sent to the Panaji office which counts to 11 such cumulative daily rainfall measurement locations in Goa. Figure 2 gives the locations where such measurements are done in Goa.

4. A Cyclone Detection Radar (CDR), capable of giving the cloud pictures up to a range of 400 km, has been functioning for a long spell of time and is phased out now. It has given way to the modern Doppler

Radar. Already six Doppler Radars have been commissioned in India and their data products are available on the IMD web site. Infrastructure facilities are being made for the commissioning of Doppler Radar in the IMD office at Altinho now and it will be set to function soon. A thing of concern here is, even though the Doppler radar is capable of furnishing very good information of the precipitable water content and the radial wind speed of every convective system in the surroundings up to a range of 400 km, it will not give the specific spot where it is going to rain. Hence, the use of Doppler Radar will be restricted to forewarning the watch keeping mechanism of any approaching cloud patch, its water content and the speed at which it is approaching.

5. IMD has so far installed two AWSs and four ARGs in Goa. These gauges are capable of measuring the rainfall at short intervals of time and hence the hourly rate of rainfall can be estimated. Figure 3 gives the locations of the AWSs and ARGs in Goa.

The AWS are commissioned at IMD, Altinho, Panaji and ICAR, Ela farm, Old Goa. The ARGs are located at Zonal Agricultural Office, Pernem, Zonal Agricultural Office, Mapusa, Navodaya Vidhyalaya, Valpoi, and Mallikarjun College of Arts and Science, Canacona.

These AWSs and ARGs are online gauges and the data collected are transmitted to their nodal centre for recording and for posting on the IMD website. Hourly data of the meteorological parameters from the AWS at Ela farm, Old Goa is made available on the IMD website now and soon the remaining also will follow. These online automatic gauges are ideal equipments for the purpose of prediction of events like intensive rainfall, cloud burst, etc. It is observed, however, that there is a constant, near-two-hour lag in updating of information. For instance, 00 UTC values are available on the IMD web site only at 02 UTC.

3.2 Indian Space Research Organization

As of 2010, ISRO has installed 14 AWSs stations in Goa; these AWSs collect rainfall data along with many other surface meteorological parameters. ISRO makes these data available online for the registered users. Meteorological and Oceanographic Satellite Data Archival Centre (MOSDAC) of ISRO is responsible for the data reception, archival and dissemination of the AWS on line data. The ISRO AWSs gauges in Goa are functioning at Verem, Dabolim, Bicholim, Pernem, Assagao, Panaji, Mapusa, Nuvem, Quepem, Canacona, Khandola, Old Goa, Margao and Taleigao. The web site of MOSDAC is nearly live and kept up to date in the sense that the AWS hourly data is uploaded within about ten minutes of the data acquisition. Figure 4 shows the spatial lay out of the ISRO AWSs in Goa.

The names of the locations and their geographical co-ordinates of the cumulative daily rainfall gauges and the AWSs and ARGs in Goa, installed and operated by IMD and ISRO, are given in Table 2.

4 Methodology

It has been already established that the 2 October 2009 Canacona disaster was the result of the sequence of events as given below.

1. Normal rainfall during 2009 monsoon season led to loading of soil with high amount of moisture.

2. The three preceding days of the fateful day witnessed 252 mm of rainfall, saturating the ground and flooding the river channels.

3. The deluge of water due to the seven-hour-long precipitation on 2 October 2009, amounting to 271 mm, cascaded down the slope of gradient 45° and above, causing the mudslides and flooding.

The havoc was basically due to the combination of the following geographical features:

1. the catchment areas being located on high lands,

2. the terrain turning into steep slopes, and

3. the landscape drops to the valley.

The topographical features of Goa comprising of hills and plains makes it vulnerable to flooding at many spots during intense-precipitation events. It is necessary to look at the topography in great detail at fine resolution necessary to suggest the locations for commissioning of more ARGs.

4.1 Altitudes and slopes

The Shuttle Radar Topography Mission, known as SRTM gives the altitude of the study area at 90 m $\times$ 90 m resolution as the output of a Digital Elevation Model (DEM). Appendix A gives some additional information on SRTM. Using these altitude values, the gradient of the whole terrain of Goa was calculated. Plotting the altitudes and the slope of the study area on an enlarged scale gives us a coarse idea of the high lands, slopes and valleys. Normally, a steep gradient is expected to favour mudslides. A valley surrounded on two or three sides by hills is susceptible to flooding, and, if the place is a settlement zone, the impact of the disaster will be felt more. Hence, installation of an AWS is suggested at such vulnerable spots.

To observe the altitude and slope variations on a fine scale, the map of Goa was divided into eight parts (Figure 5). Due care was taken to separate out the western ghats and coastal plains, as plotting a high elevated mountain range and a low-lying plain in the same plot would reduce the resolution because the scale chosen for plotting the altitude or slope will have to cover a large range. Hence, to avoid such situations, the plains and the high ranges were separated out to the maximum extent possible. In spite of this, while plotting segment VII, the Karmal Ghat and the coastal plains appear together: they could not be segregated owing to their geographical orientation. Figures 6 and 7 show the altitude and slope, respectively, for the whole of Goa. Two different sets of figures of the subdivided eight segments have been prepared to show the altitude and slope variations of the terrain of each of the segments. The altitude plots of all the eight segments are shown in Figures 8–15, corresponding to the sub-divisions I to VIII. Just three slope plots are shown (Figures 16–18), which correspond to the altitude plots in Figures 8, 9, and 14 (for sub-divisions I, II, and VII). The altitude plots were used to identify the vulnerable areas and the slope plots were used to support the analysis.

4.2 Identification of the locations

Having seen the altitude and slope variations over the study area, we had to pinpoint the vulnerable zones by the names of the locations. A thickly populated settlement area that lies at the foot of an elevated land, or a settlement surrounded by high ranges, will suffer greater loss of human lives and more property loss. Hence, the settlement zones had to be identified and plotted on the altitude and slope plots. Two popular softwares, Google Earth and Google Maps, have been used judiciously to get that information. Refer to Appendix B for additional information on Google Earth and Google Maps.

Google Earth gives the topographical features at a fine level of detail. In addition, the latitude and longitude values at any place can be obtained by moving the cursor over the satellite-captured landscape. Google Earth displays the latitude and longitude information of the point over which the cursor is placed. Google Map gives the fine details of the populated areas with their names labelled. It can toggle between a plain map surface displaying only the settlement zones and roads and the same map on the satellite-captured earth surface. As the satellite imagery of both Google Earth and Google Map use the same data base, if both display the same study area at the same scale, the displayed features of the study area from both the images can be compared and the position details of any spot on Google Map may be found using Google Earth. Using these two softwares simultaneously, 64 preliminary spots were picked up from Google Map as vulnerable locations, which are either thickly populated areas or steep gradient regions, and their respective co-ordinate details were picked up from Google Earth.

4.3 Logic of choosing a new site

As stated earlier, the catchment areas for the flooding events are high lands or steep hills, and the areas vulnerable to floods are the adjoining low-lying plains and valleys. If the affected area happens to be a thickly populated area on plains surrounded by hills, greater number of deaths and higher property loss will result. If the same plain surrounded by hills happens to be agricultural land, the mudslides and the flood cover the cultivable fields and make them unfit for cultivation. Hence, such a combination of plain, surrounded by elevated table land or hills, were visually located and marked as flood-vulnerable zones.

These preliminary spots were posted on the altitude and slope plots of the eight segments that were prepared using the SRTM DEM output. Each new gauge after installation at these new sites will have its own zone of representation and will serve as a weather-monitoring device for that particular area. As suggested earlier, redundancy in data collection is not desirable. Hence, no two new sites should lie close to each other. To verify that fact, the locations of the AWSs and ARGs operated by IMD and the AWSs operated by ISRO were gathered from the website or from their respective offices, and these locations were also posted on the same altitude and slope figures. The markings were done with symbols unique to each kind. Refer to the figures for details. A black star is a suggested site for a new AWS. A red star means it is desirable to have a new AWS at that location, but the existence of an IMD or ISRO gauge in the vicinity implies that it is eliminated from the list of sites for new AWSs. An exemption to this rule was made at Valpoi, where, in spite of the existence of an ARG of IMD, commissioning of a new AWS is proposed. This is due to the chronic history of repeated events of flooding at Bicholim and its surroundings every year during the monsoon.

While plotting, an optimum range has been chosen for the colour palette for the altitude and slope in order to give the maximum detail of the landscape. Though an attempt was made to avoid having a location with an altitude or slope beyond the range,it was not possible to eliminate all such patches, which appear as white patches in some figures. These patches are either low-lying water bodies or places with altitude beyond the maximum range of the scale. An example is in Figure 14, in which some white patches on the top of the high ranges in the Karmal Ghat regions are seen as they are not covered by the altitude range chosen for the colour scale. The landscape of the study area is quite uneven in that we have large coastal plains and elevated table lands or promontories located quite close to each other. The range of the altitude or slope chosen should cover all the variations of the topographical details of the highlands as well as the coastal plains. The need to resolve well the more important features, however, implied that a slightly lower value had to be chosen in some figures; the result is white patches as in Figure 14.

It may be seen in Figure 8 that Pernem and Mapusa are the desired sites for the installation of a new AWS, but a red star, indicating no new installation, is shown there because these locations have already both the IMD and ISRO gauges functioning. Saligao is placed by the side of high lands and Siolim is seen sandwiched between two elevated landscapes. Hence, these are marked as vulnerable spots. In Figure 10, Sanquelim, Sateri, Virdi, Chorla, and Valpoi are chosen because they are either thickly populated areas or catchment areas. As already stated, Valpoi is a site suggested for the installation of a new gauge in spite of the existence of the IMD ARG there. Similarly, Canacona (Figure 14) is a site where it is desirable to have a new gauge installed, but it already has an ARG operated by IMD and an AWS operated by ISRO. Nevertheless, in order to cover the large plain and the valleys at the foot of the Karmal ghat stretch,a new site is recommended at Partagol.

4.4 List of suggested locations of the new AWSs and ARGs

After completing all these exercises, a total of just 14 locations have been identified for the new AWS/ARG installations. The list of these locations and their co-ordinates are given in Table 3. The suggested locations are Valpoi, Sanquelim, Sateri, Chorla, Virdi, Partagol, Sanguem, Mollem, Tisk, Ponda, Verna, Loutulim, Siolim, and Saligao. Of these 14 locations, sites 1–10 are considered as high-priority zones on the basis of the following facts. They are locations with a past history of mudslides and/or flooding events and there are not enough weather-observing systems in the vicinity. Locations 11–14 are given second priority because, though they are identified as flood-vulnerable zones from the altitude and slope plots, they

1. do not have any past history of flooding,

2. have weather-observing systems within a reasonable distance, and

3. are located near the coast.

Figure 19 shows all the locations of the proposed sites for the commissioning of new AWS or ARG and Figure 20 gives the final network of the AWS and ARG once all the AWSs proposed are put in place.

5 Recommendations

1. The web sites of both the IMD and the ISRO were monitored for about a week. It was noticed that IMD seems to be updating its site with a lag of two hours. ISRO AWS data are mostly uploaded within about 10 minutes. It may be recalled that during the 2 October 2009 Canacona disaster, we observed from the ISRO AWS at Canacona that the intense rainfall started at about 0900 hrs. Later during the survey, we learnt from the people of the affected villages that the water level started rising by about 1100 hrs. It needs to be emphasized here that there is hardly two hours of warning time. In such conditions, every minute makes a big difference in the evacuation and salvage operations that are a part of preparedness. Hence, some arrangement needs to be made by the concerned authorities for the nodal centre to get live data from the IMD weather-observing systems. It needs to be done at least for the gauges at the locations where the flooding events are chronic and mudslides have been reported in the past.

2. The IMD Doppler Radar is capable of issuing a warning of the approach of a cloud patch with the details of its precipitable water content and the radial wind speed up to a range of 400 km. The severity of the parameters will indicate the impending intense-rainfall event and how long the *round-the-clock watch* to look for the likelihood of the disasters is going to be. Hence the combination of the Doppler Radar, existing AWSs and ARGs, and the proposed new AWSs will make a good network of observing systems. It then becomes the job of the personnel at a suitable nodal centre receiving adequate live data from

the AWS network, to assess the scenario using the incoming data and the flood-risk assessment software. This assessment will lead to the decision on issuing alerts to set in motion the disaster-preparedness and disaster-mitigation plans of the administration.

3. The new AWS sites must be

   (a) stable, so that the gauge itself will not be affected by extremes of the weather,

   (b) safe, in the sense that theft and pilferages must be watched for, and

   (c) must have reasonable access for routine maintenance.

   At the time of actual commissioning of a new AWS, it may be felt necessary or preferable to shift the site to a more convenient location owing to operational reasons. The locations suggested here are indicative and some changes will not matter provided due care is taken to ensure that the gauge is representative of the locality for which it is suggested.

4. Finally, it must be remembered that much of Goa's rainfall occurs on the thinly populated slopes of the western ghats. In order to permit an estimate of the state's water resources and to complete the rainfall-measuring network for Goa, it is suggested that a few AWSs be commissioned and operated on the hill slopes along the full stretch of the Ghats.

6 Conclusion

In summary, we propose a watch-keeping mechanism comprising the following.

1. A Doppler Radar in place to look far, up to a range of 400 km from the base, to forewarn the watch keepers of the approach of any convective system.

2. A network of automatic weather-observing systems, as suggested above, to provide the necessary adequate live input data on rainfall to the flood-risk assessment software.

3. A nodal centre to receive the online input data from the network of weather−observing systems to gauge the impending flood risk, operating at the office of IMD at Panaji.

4. A dedicated watch-keeping team functioning at IMD, Panaji to observe *round-the-clock* watch in case any large meteorological system is shown by the Doppler Radar. They will start analysing the incoming weather data from the online gauges critically to assess the situation at all the locations simultaneously and to raise a red alert on sensing any likelihood of a disaster.

5. A multifaceted team, to act on the *red alert*, to evacuate the residents of the areas, for which the red alert is raised and which are under the threat of mudslide or flood or both possibilities. This team will be responsible for the rescue operations also when the need arises. This team must be able to take its own decisions on the spot on demand.

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Appendix A The Shuttle Radar Topography Mission (SRTM)

[1]The Shuttle Radar Topography Mission (SRTM) (`http://www.jpl.nasa.gov/srtm/`) is an international research effort to getdigital elevation models on a global scale from 56° S to 60 ° N, to generate high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system that flew on board the Space Shuttle Endeavour during a 11-day mission in February 2000, based on the older Space borne Imaging Radar-C/X-band Synthetic Aperture Radar. To acquire topographic (elevation) data, the SRTM payload had two radar antennas. One antenna was located in the Shuttle's payload bay, the other on the end of a 60-meter (200-foot) mast that extended from the payload bay once the Shuttle was in space. The technique employed is known as *Interferometric Synthetic Aperture Radar*.

The elevation models are arranged into tiles, each covering one degree of latitude and one degree of longitude, named according to their south western corners. The resolution of the cells of the source data is one arc second, but $1''$ ($\sim$ 30 m) data have only been released over United States territory; for the rest of the world, only three-arc-second (approximately 90 m) data are available. The elevation models derived from the SRTM data are used in Geographic Information Systems. They can be downloaded freely over the Internet, and their file format (`.hgt`) is supported by several softwares. The Shuttle Radar Topography Mission is an international project spearheaded by the United States National Geospatial-Intelligence Agency (NGA) and National Aeronautics and Space Administration (NASA). The elevation datasets are affected by mountain and desert no-data areas. These amount to no more than 0.2% of the total area surveyed, but can be a problem in areas of very high relief. They affect all summits over 8,000 meters, most summits over 7,000 meters, many Alpine and similar summits and ridges, and many gorges and canyons. Groups of scientists have worked on algorithms to fill the voids of the original SRTM data. Two datasets offer global coverage of

[1]Information courtesy: Wikipedia, the free encyclopedia

void-filled SRTM data at full resolution.

Appendix B Google Earth and Maps

[2]*Google Earth* (http://earth.google.com/) is a virtual globe, map and geographic information program that was originally called Earth Viewer $3D$, and was created by Keyhole, Inc, a company acquired by Google in 2004. It maps the Earth by the superimposition of images obtained from satellite imagery, aerial photography and GIS $3D$ globe. Google Earth is a free version.There are two other versions meant for commercial applications on payment.

Google Earth displays satellite images of varying resolution of the Earth's surface, allowing users to see things like cities and houses looking perpendicularly down or at an oblique angle, with perspective. The degree of resolution available is based somewhat on points of interest and popularity, but most land, except for some islands, is covered at least 15 m resolution. Google Earth allows users to search for addresses for some countries, enter coordinates, or simply use the mouse to browse to a location.

For large parts of the surface of the Earth, only $2D$ images are available from almost-vertical photography. Viewing this from an oblique angle, there is a perspective in the sense that objects which are horizontally far away are seen smaller, but of course it is like viewing a large photograph, not quite like a 3D view. For other parts of the surface of the Earth $3D$ images of terrain and buildings are available. Most land areas are covered in satellite imagery with a resolution of about 15 m per pixel. This base imagery is 30 m multi -spectral landsat which is pan-sharpened with the 15 m Landsat imagery.

However, Google is actively replacing this base imagery with 2.5 m spot imagery and several higher resolution datasets.

Google Maps (http://maps.google.com/) is a web-mapping service application and technology provided by Google. Available free (for non-commercial use), it powers many map-based services. It offers street maps, a route planner for travelling by foot, car, or public transport, and an urban

[2]Information courtesy: Wikipedia, the free encyclopedia

business locator for several countries around the world. Google Maps uses a close variant of the Mercator projection; hence, it cannot show areas around the poles. A related product is Google Earth, a stand-alone program which offers more globe-viewing features, including polar areas.

Google Earth and Google Maps have been condemned for their information content by various governments as having potential for misuse. Hence, Google has blurred some areas for security. Although Google uses the word satellite, most of the high-resolution imagery is an aerial photography from aircraft rather than from satellites. The main Google Maps site includes a local search feature, which can be used to locate businesses of a certain type in a geographic area. The map uses the Mercator projection, which distorts the relative surface area of regions that are far apart in latitude. This is only a concern for maps of whole continents or the entire earth, and does not affect normal use for local mapping.

References

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Stations	Cumulative Daily Rainfall (mm)			
	29 September	**30 September**	**1 October**	**2 October**
Canacona	89.0	35.8	127.4	380.0
Quepem	90.4	34.0	180.4	220.8
Sanguem	56.0	41.0	29.4	250.8
Madgaon	52.0	70.3	40.3	275.0
Ponda	54.4	56.7	23.6	227.2
Mormugao	60.9	45.2	75.9	213.1

Table 1: Cumulative rainfall recorded at the IMD stations located at six sites in South Goa over four days. A comparison shows that the rainfall is sporadic and there is no pattern in spite of the rain-gauge stations being closely spaced.

Location	IMD Gauge Location		AWS/ARG	ISRO AWS Location	
	Latitude	Longitude		Latitude	Longitude
Panaji	$15°29'$	$73°49'$	AWS	$15°28'$	$73°49'$
Mapusa	$15°35'$	$73°49'$	ARG	$15°36'$	$73°49'$
Pernem	$15°43'$	$73°47'$	ARG	$15°42'$	$73°49'$
Ponda	$15°24'$	$74°01'$			
Valpoi	$15°34'$	$74°08'$	ARG		
Dabolim	$15°22'$	$73°50'$		$15°23'$	$73°49'$
Margao	$15°17'$	$73°58'$		$15°17'$	$73°59'$
Marmugao	$15°23'$	$73°49'$			
Quepem	$15°13'$	$74°04'$		$15°14'$	$74°04'$
Sanguem	$15°14'$	$74°09'$			
Canacona	$15°01'$	$74°03'$	ARG	$14°59'$	$74°04'$
Old Goa			AWS	$15°30'$	$73°54'$
Verem				$15°30'$	$73°48'$
Bicholim				$15°36'$	$73°59'$
Assagao				$15°35'$	$73°50'$
Nuvem				$15°19'$	$73°57'$
Khandola				$15°31'$	$73°57'$
Taleigao				$15°28'$	$73°49'$

Table 2: Existing weather-observing systems in Goa. The table lists the locations and the co-ordinates (latitude is in degrees north and longitude in degrees east) of the cumulative daily gauges and AWS/ARG installations operated by IMD and ISRO.

S.No.	Name of the Location	Latitude	Longitude
1	**Valpoi**	15° 32′	74° 08′
2	**Sanquelim**	15° 34′	74° 01′
3	**Sateri**	15° 37′	74° 04′
4	**Chorla**	15° 39′	74° 09′
5	**Virdi**	15° 39′	74° 05′
6	**Partagol**	15° 00′	74° 07′
7	**Sanguem**	15° 13′	74° 10′
8	**Mollem**	15° 23′	74° 11′
9	**Tisk**	15° 26′	74° 01′
10	**Ponda**	15° 24′	74° 01′
11	**Verna**	15° 21′	73° 56′
12	**Loutulim**	15° 20′	73° 59′
13	**Siolim**	15° 37′	73° 47′
14	**Saligao**	15° 33′	73° 48′

Table 3: The table gives the final list of the suggested locations (latitude is in degrees north and longitude in degrees east) of the new AWSs and ARGs. Locations 1–10 are rated as high priority zones as these either fall at highly vulnerable zones and their past history of flooding events and also due to their location being scarce of weather observing systems in the vicinity. Locations 11–14 are not as vulnerable.

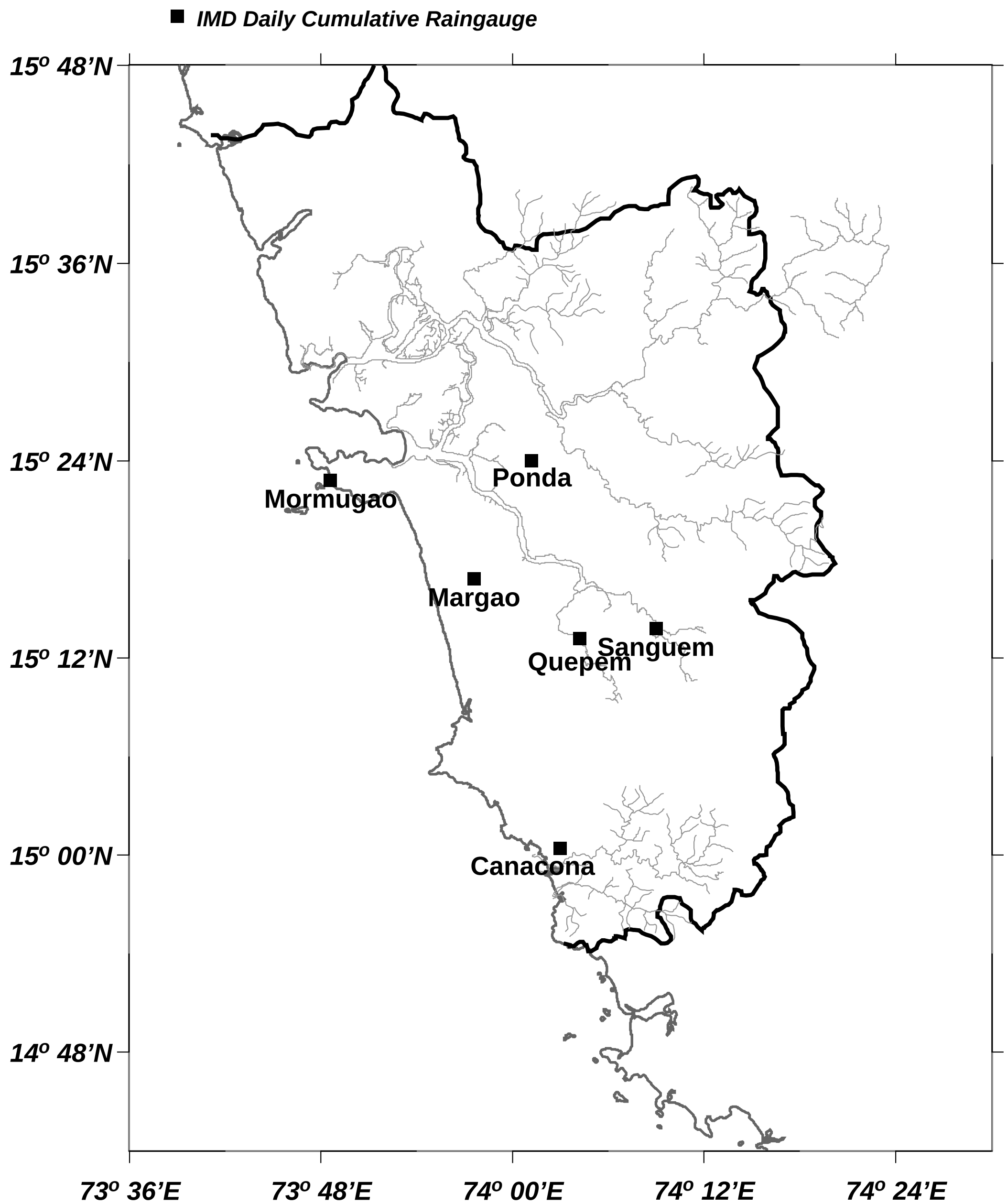

Figure 1: Locations of the IMD Daily Cumulative Rainfall gauges in South Goa. In spite of their being geographically so close, the daily rainfall at these locations shown in Table 1 show considerable differences.

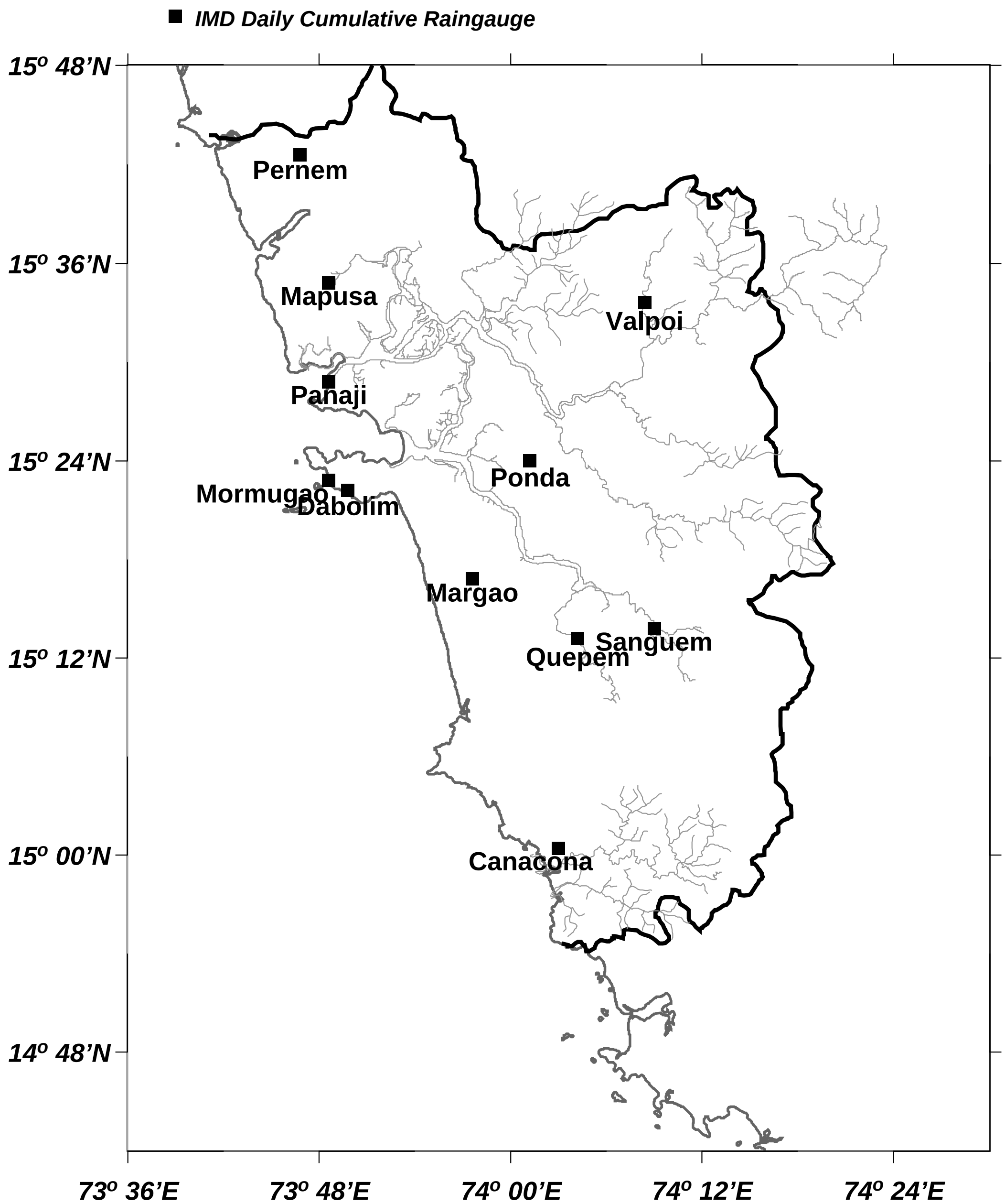

Figure 2: Locations of the IMD Daily Cumulative Rainfall gauges in Goa.

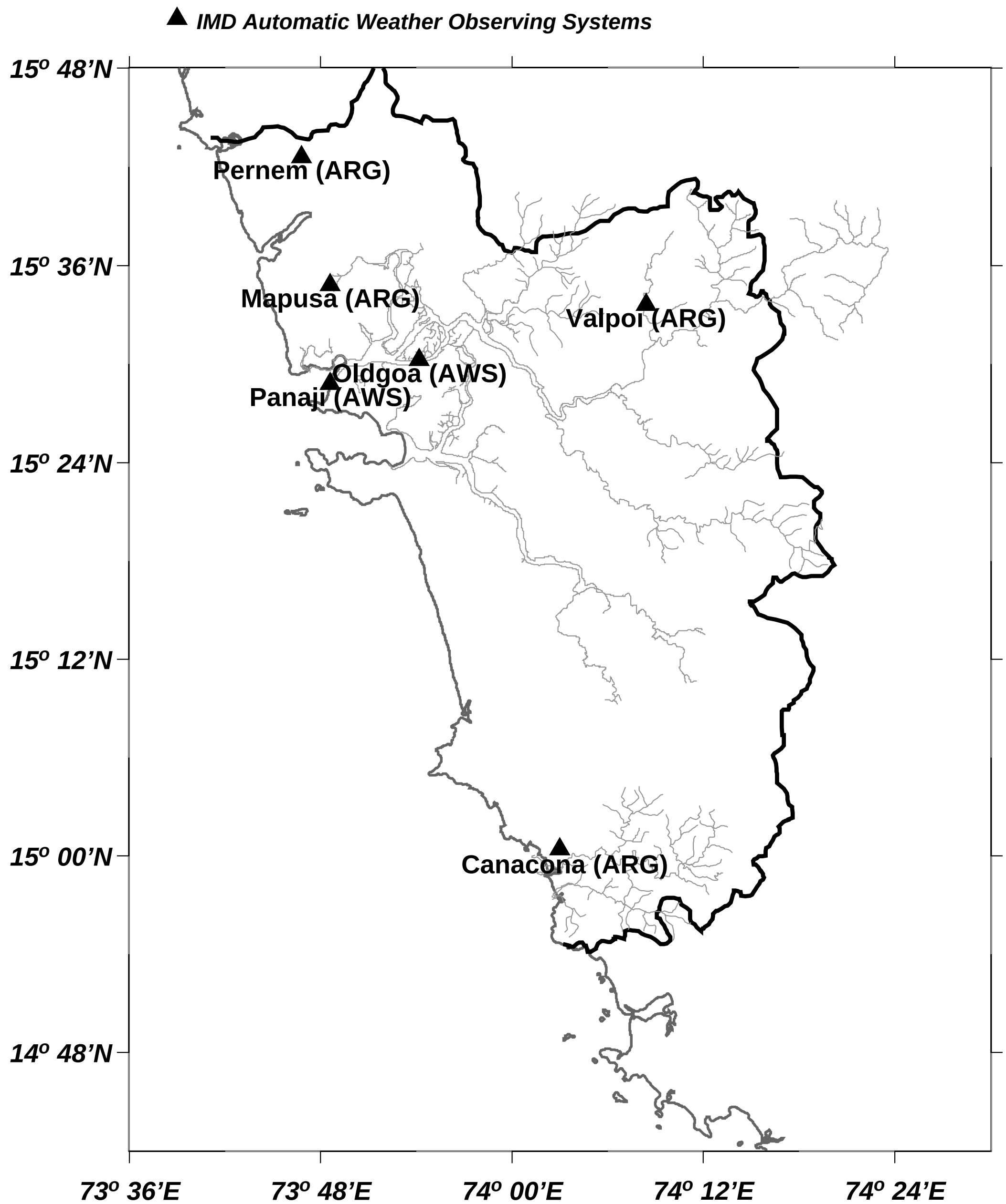

Figure 3: Locations of the IMD Automatic Weather Stations and Automatic Rainfall Gauges in Goa.

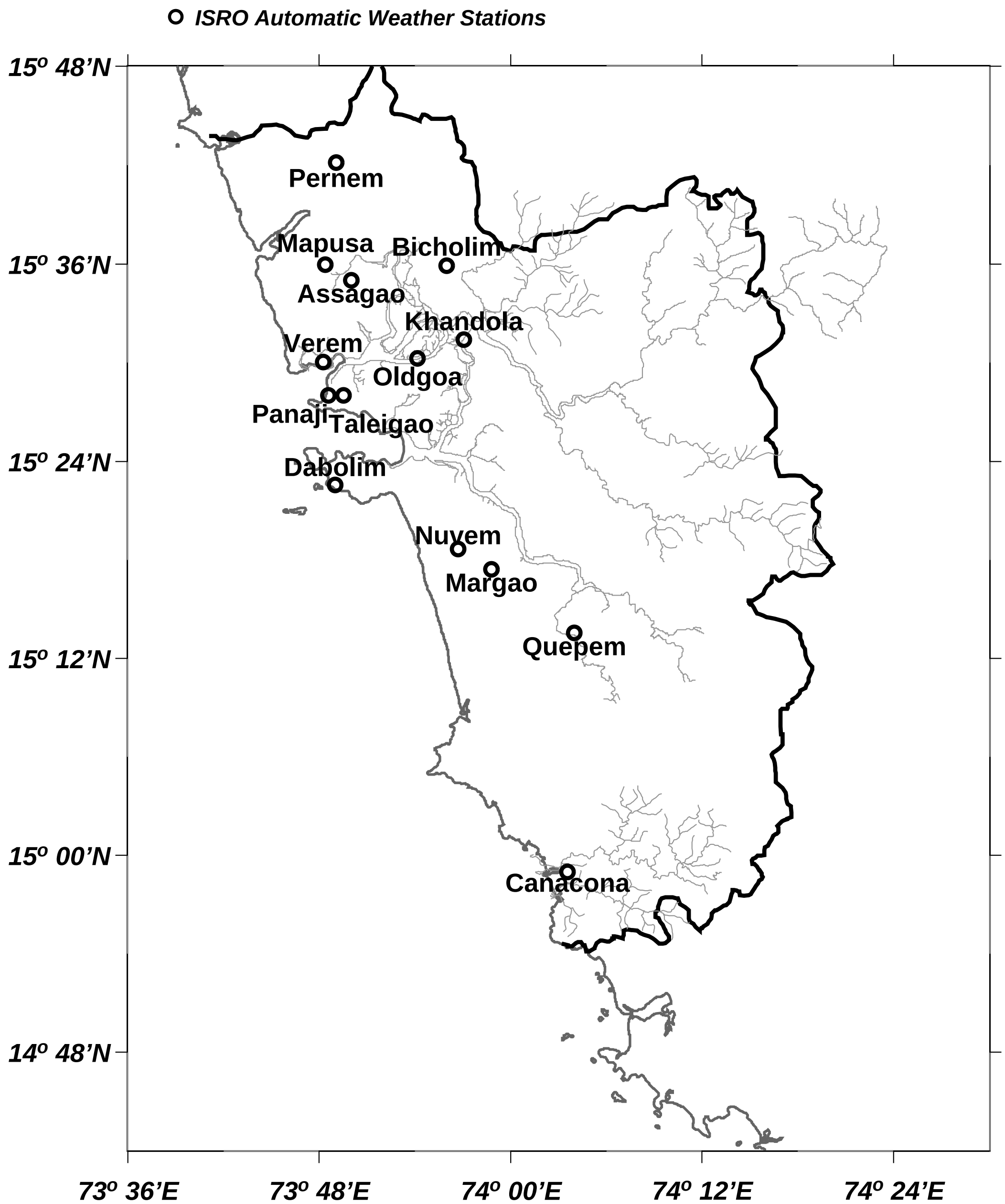

Figure 4: Locations of all the ISRO Automatic Weather Stations in Goa.

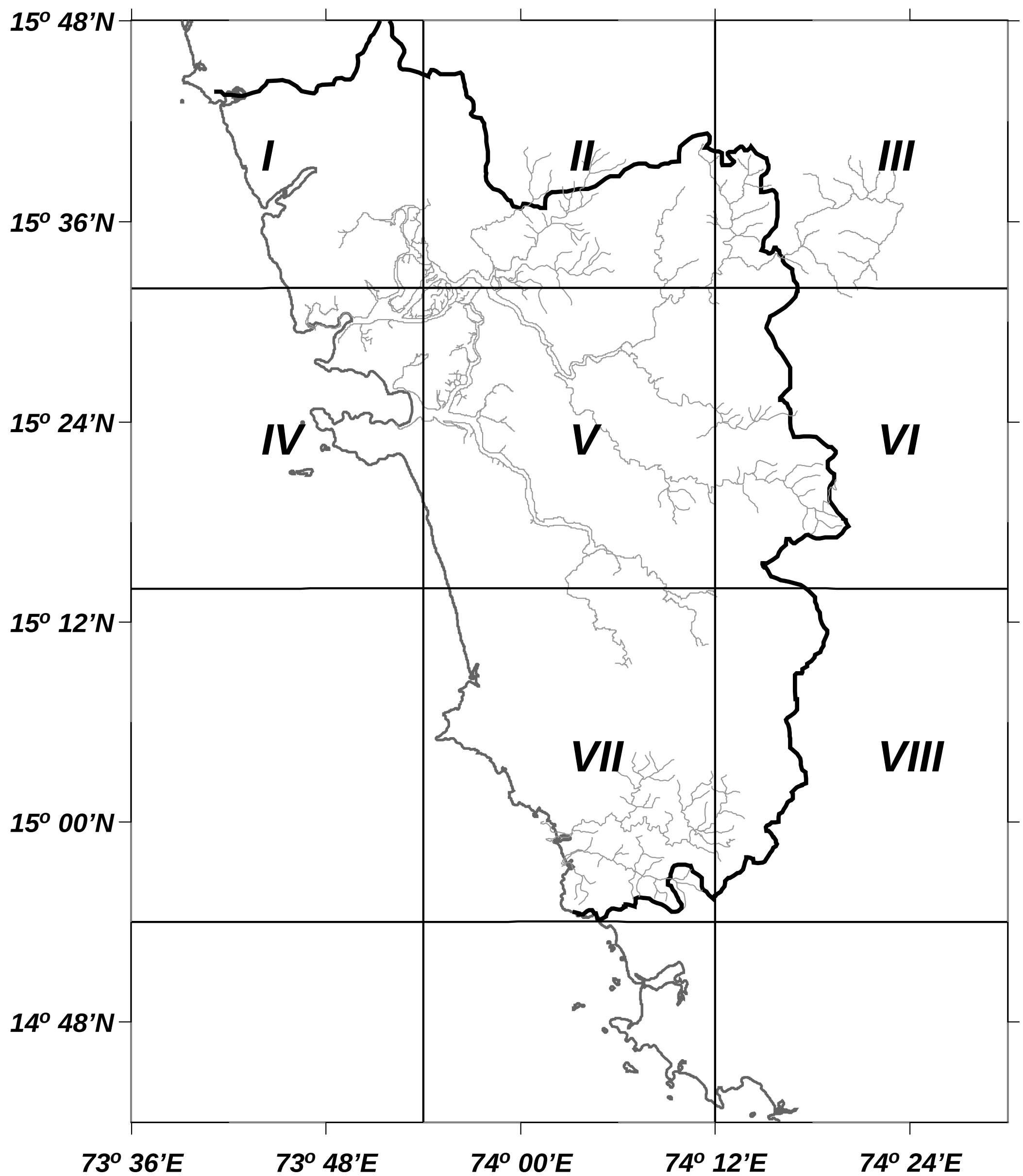

Figure 5: To enable detailed observation of altitude and slope of the terrain of Goa,the region was divided into eight sub-divisions, which are shown here.

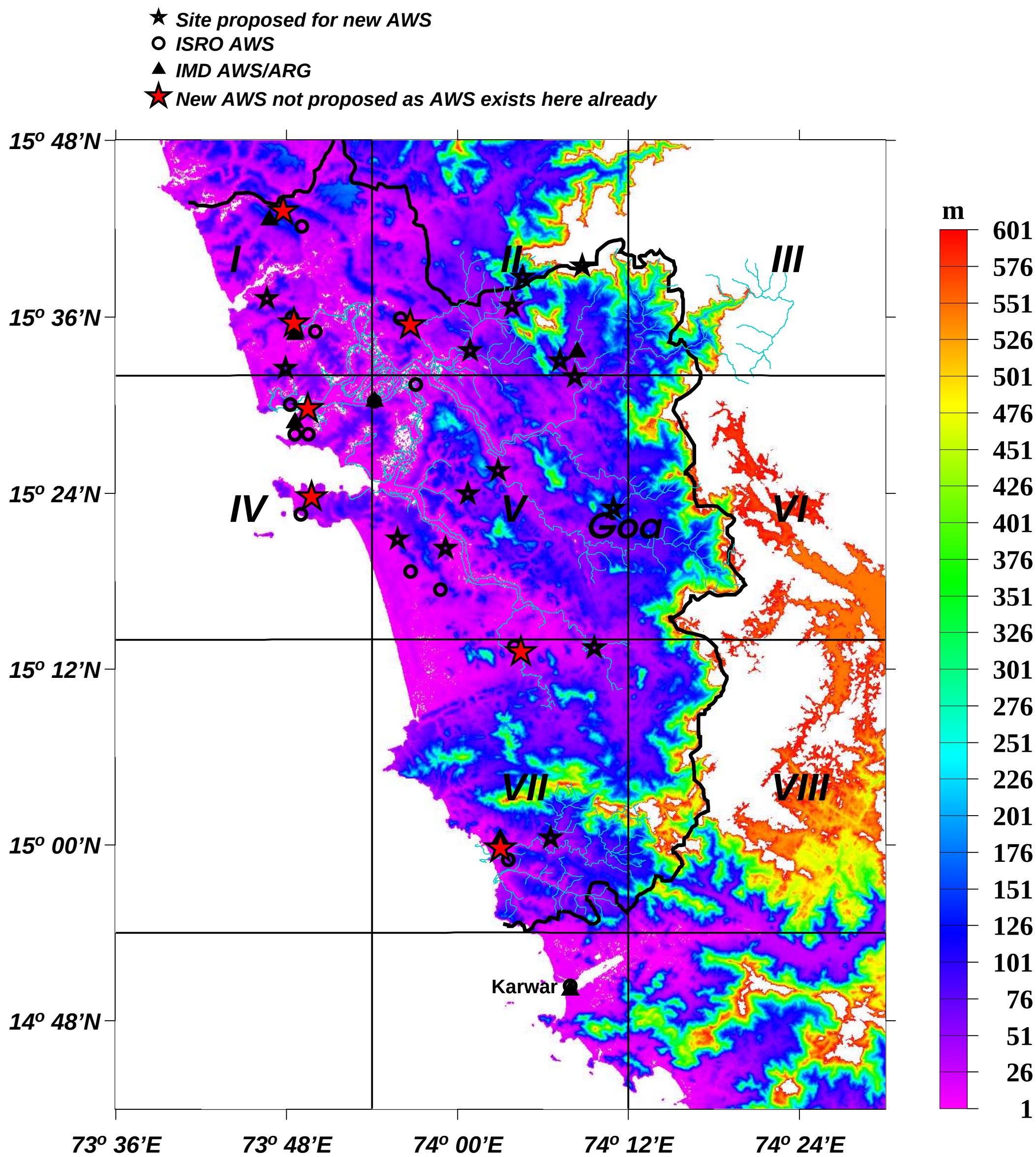

Figure 6: Altitude (in metres) in Goa obtained from the SRTM DEM. The eight subdivisions are shown. The locations of the existing IMD and ISRO Automatic Gauges and the proposed sites for the new Automatic Weather Observing Systems are also shown.

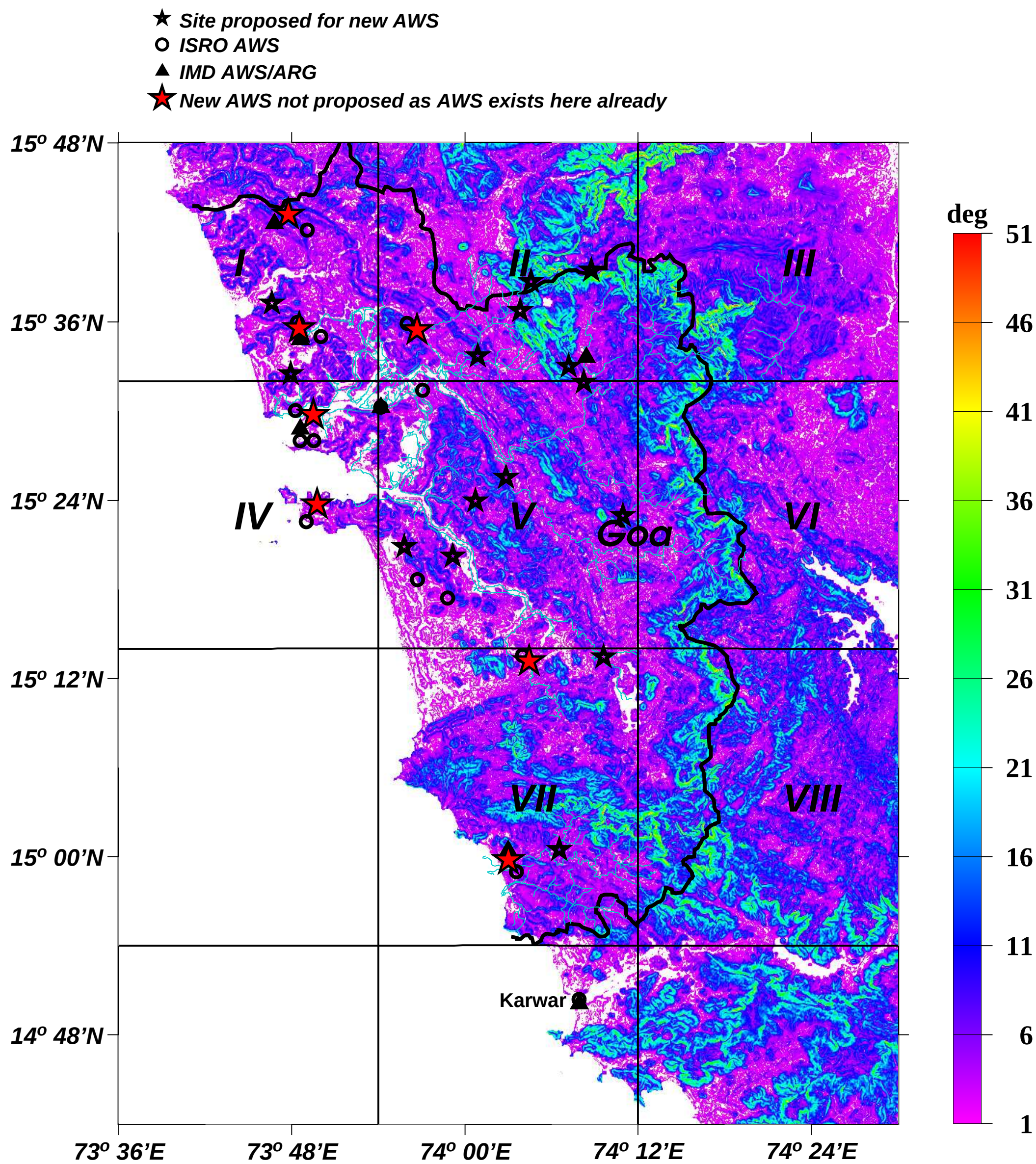

Figure 7: Slope (in degrees), estimated using the SRTM DEM. The eight sub-divisions are shown. The locations of the existing IMD and ISRO Automatic Gauges and the proposed sites for the new Automatic Weather Observing Systems are also shown.

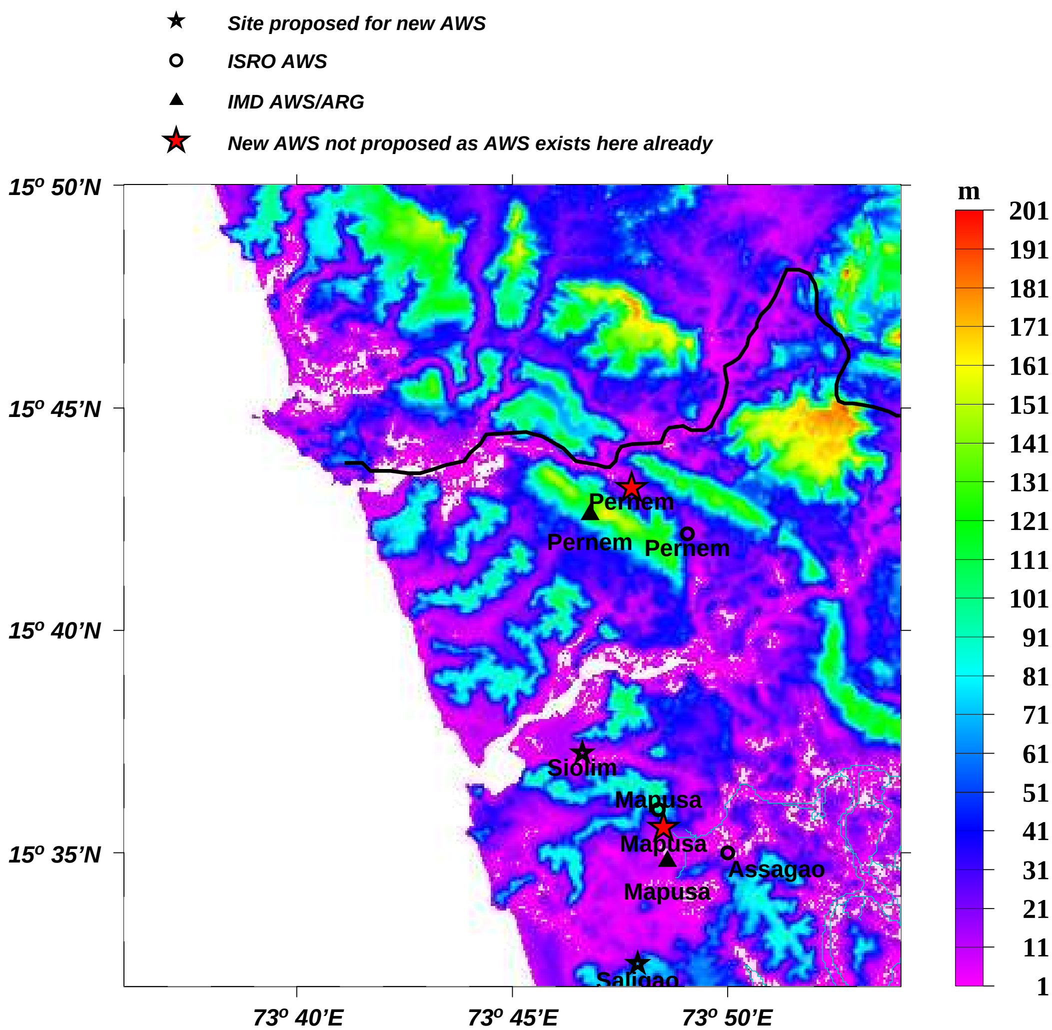

Figure 8: Altitude (in metres) obtained from the SRTM DEM for subdivision I. The locations of the existing IMD and ISRO Automatic Gauges and the proposed sites for the new Automatic Weather Observing Systems are superimposed with different symbols.

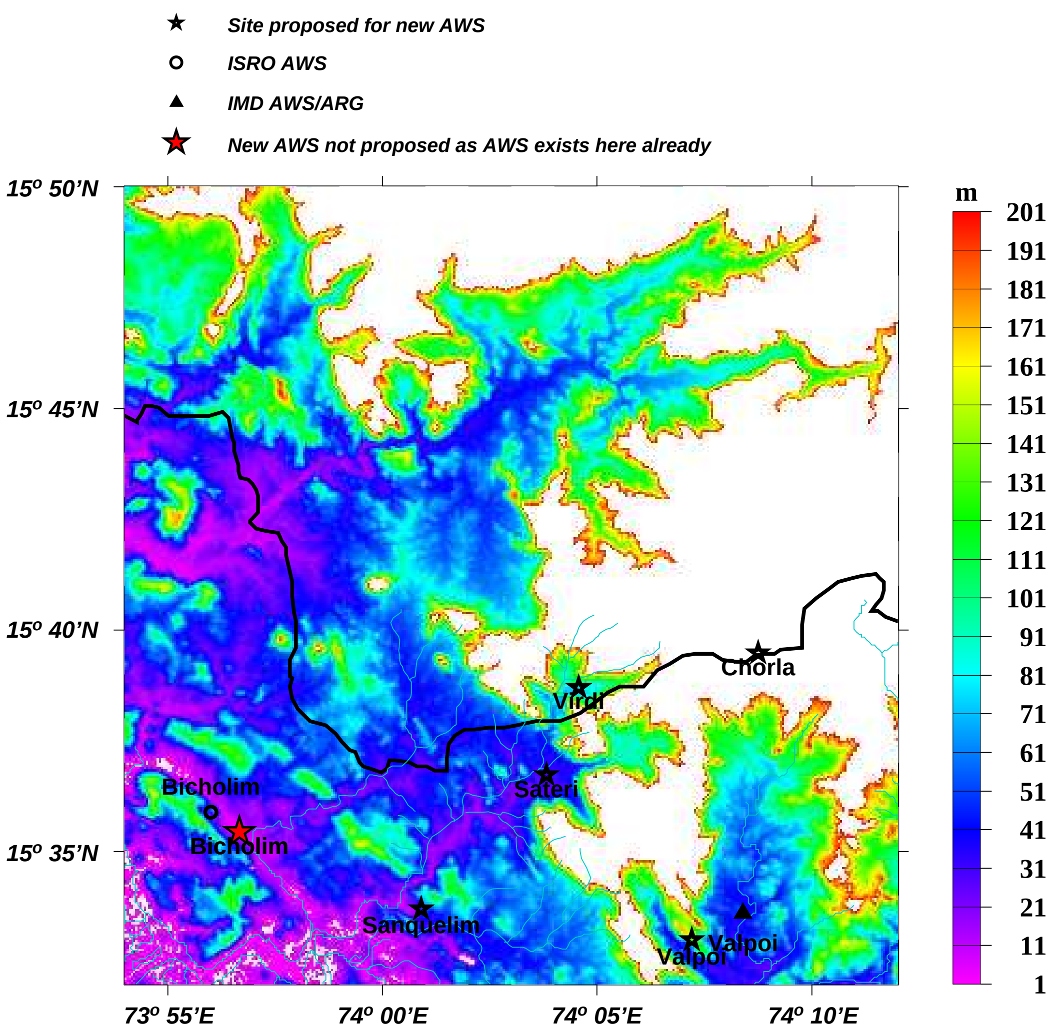

Figure 9: Same as Figure 8, but for sub−division II.

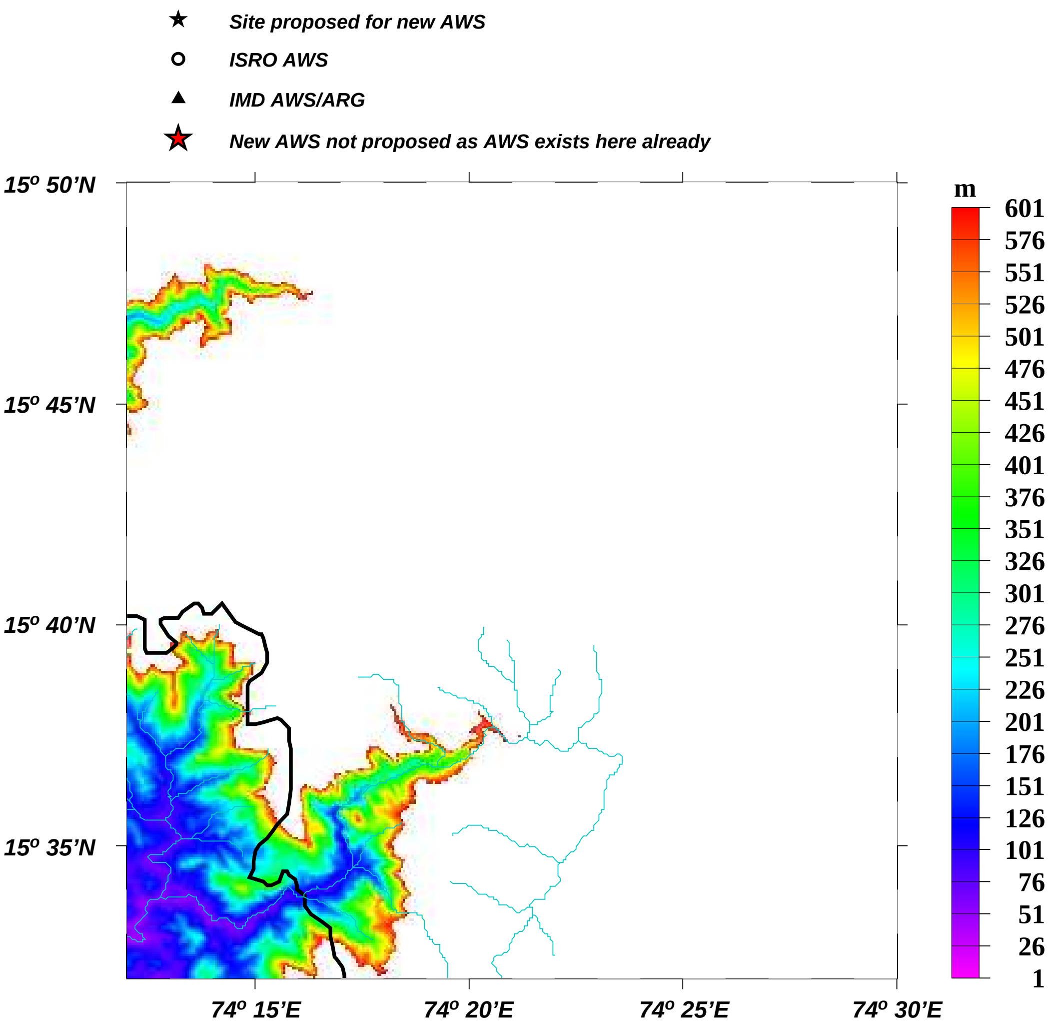

Figure 10: Same as Figure 8, but for Sub−division III.

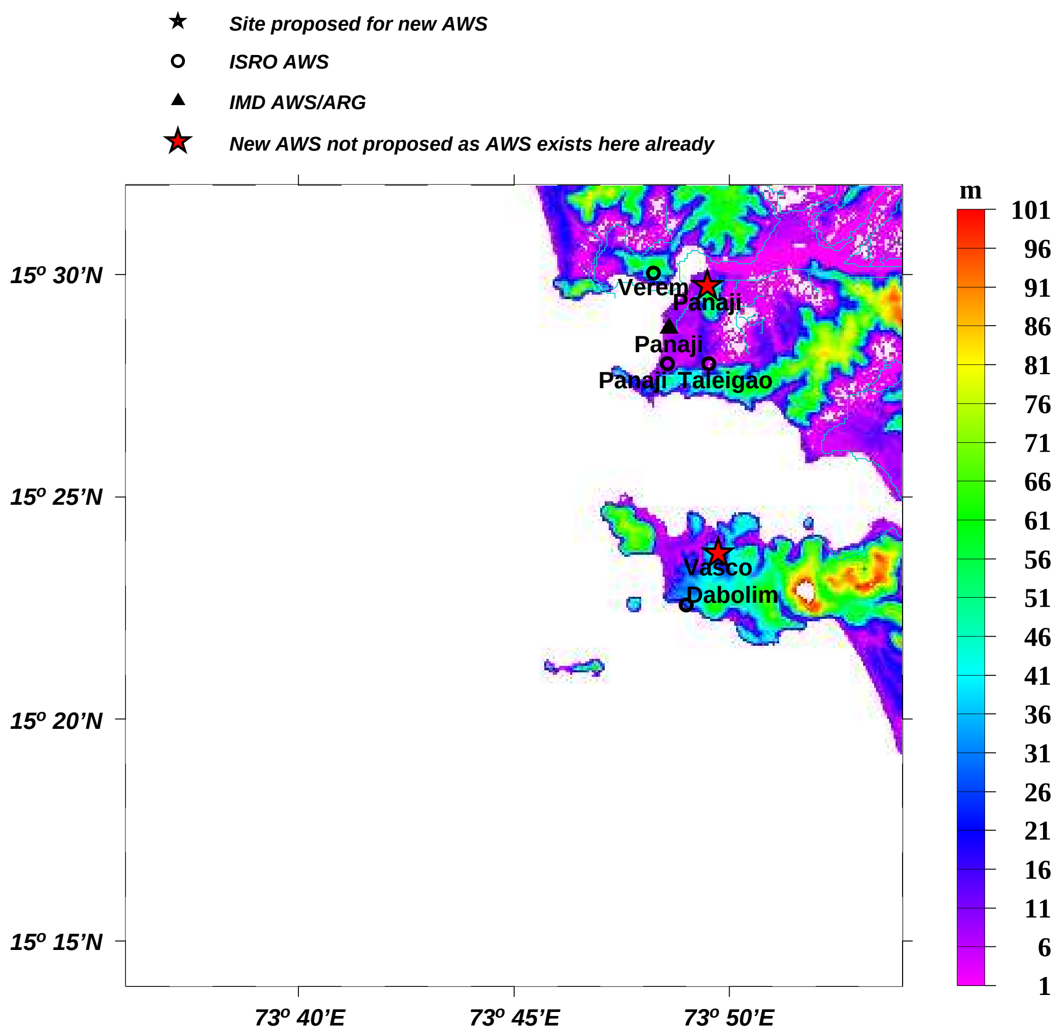

Figure 11: Same as Figure 8, but for Sub−division IV.

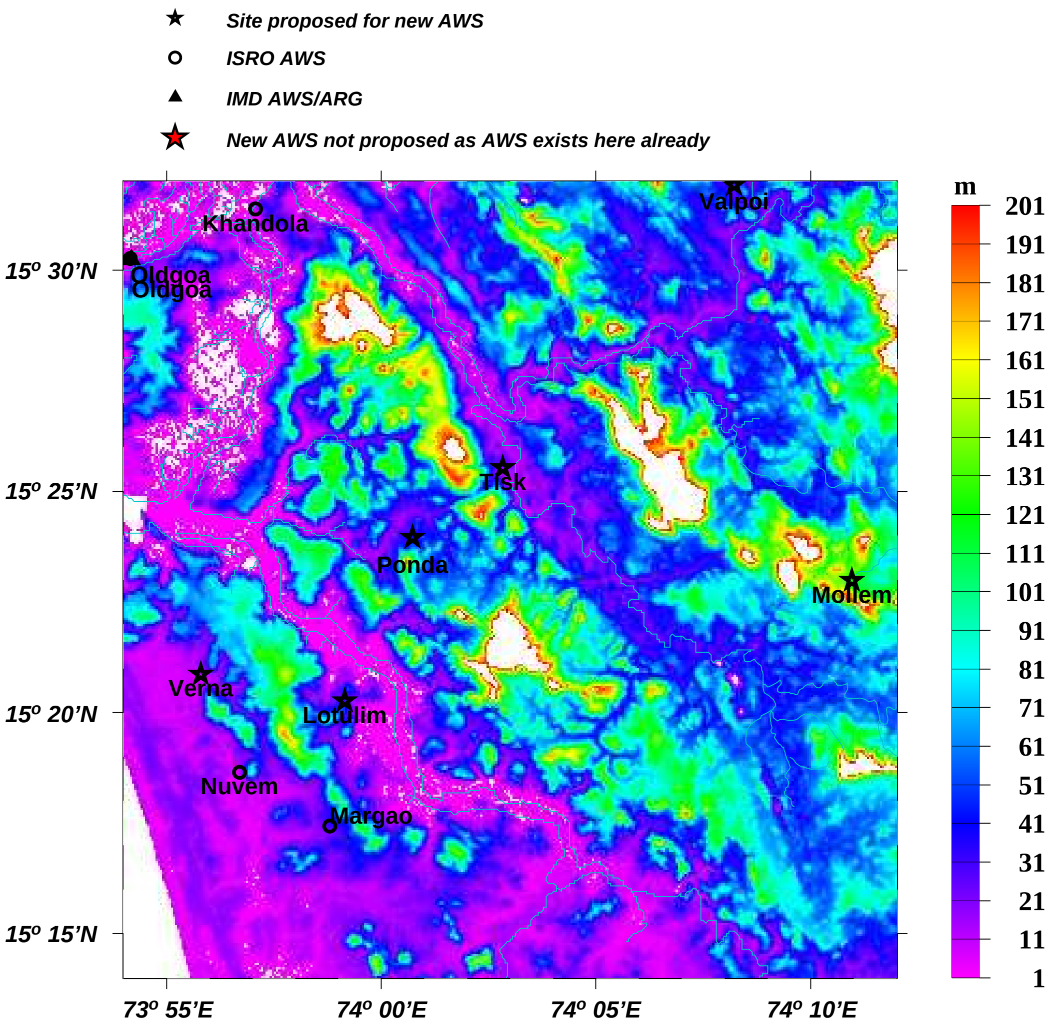

Figure 12: Same as Figure 8, but for Sub−division V.

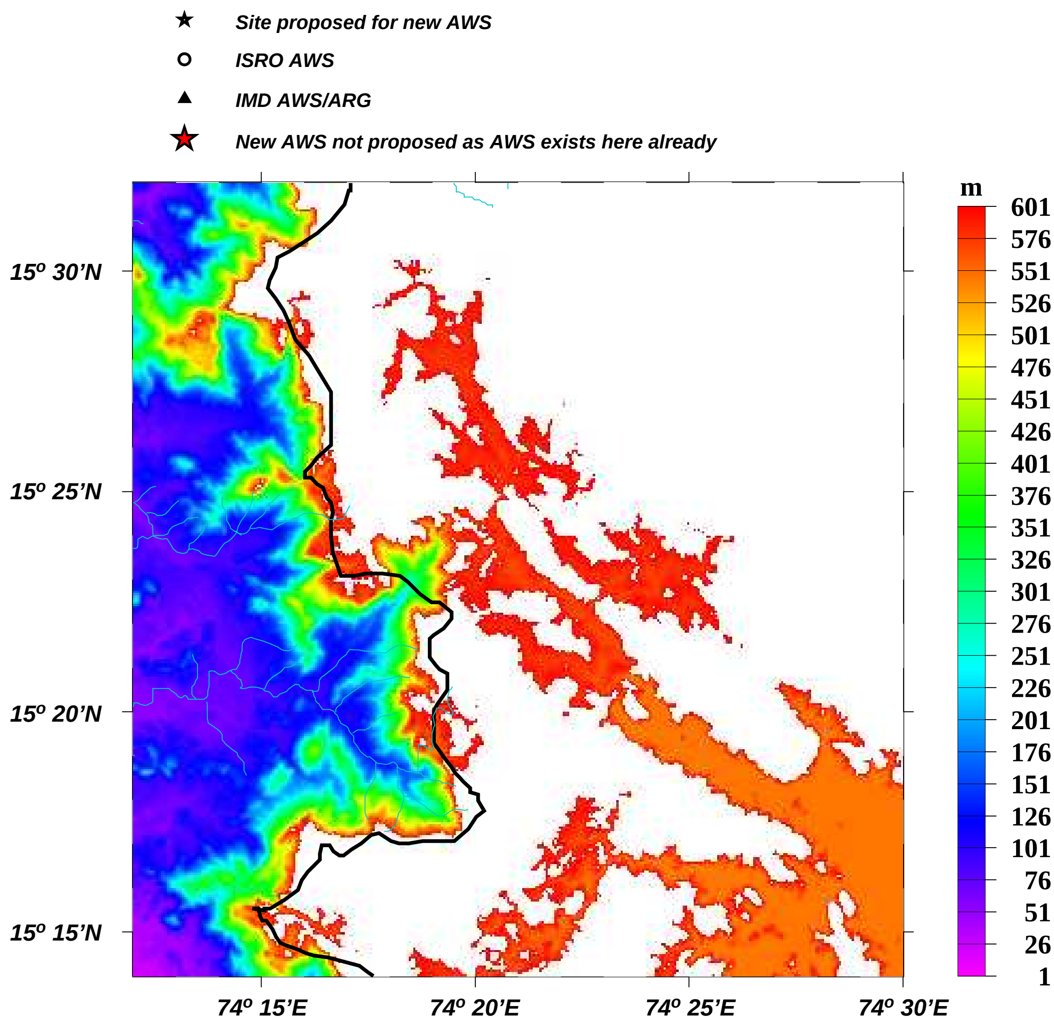

Figure 13: Same as Figure 8, but for Sub-division VI alone.

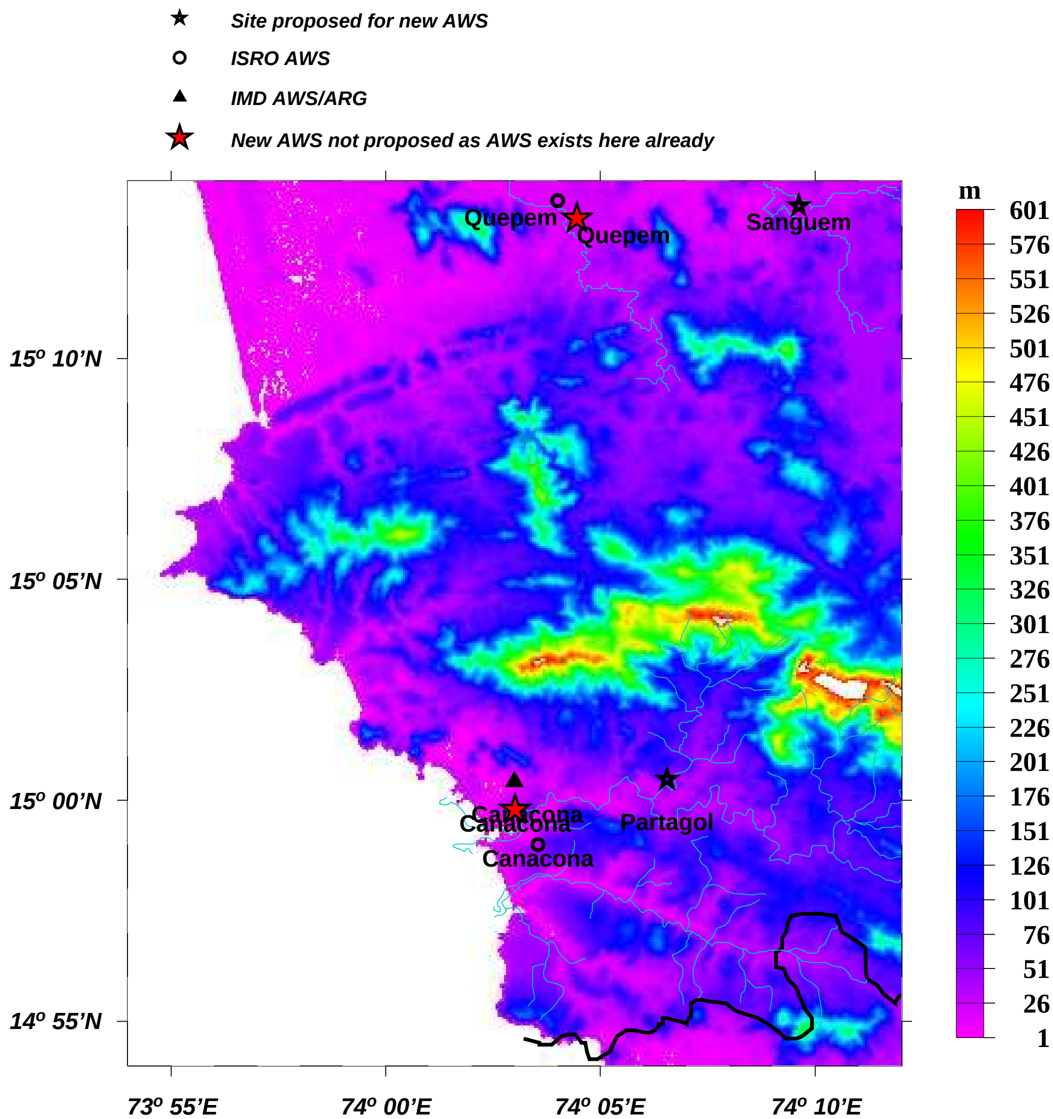

Figure 14: Same as Figure 8, but for Sub-division VII.

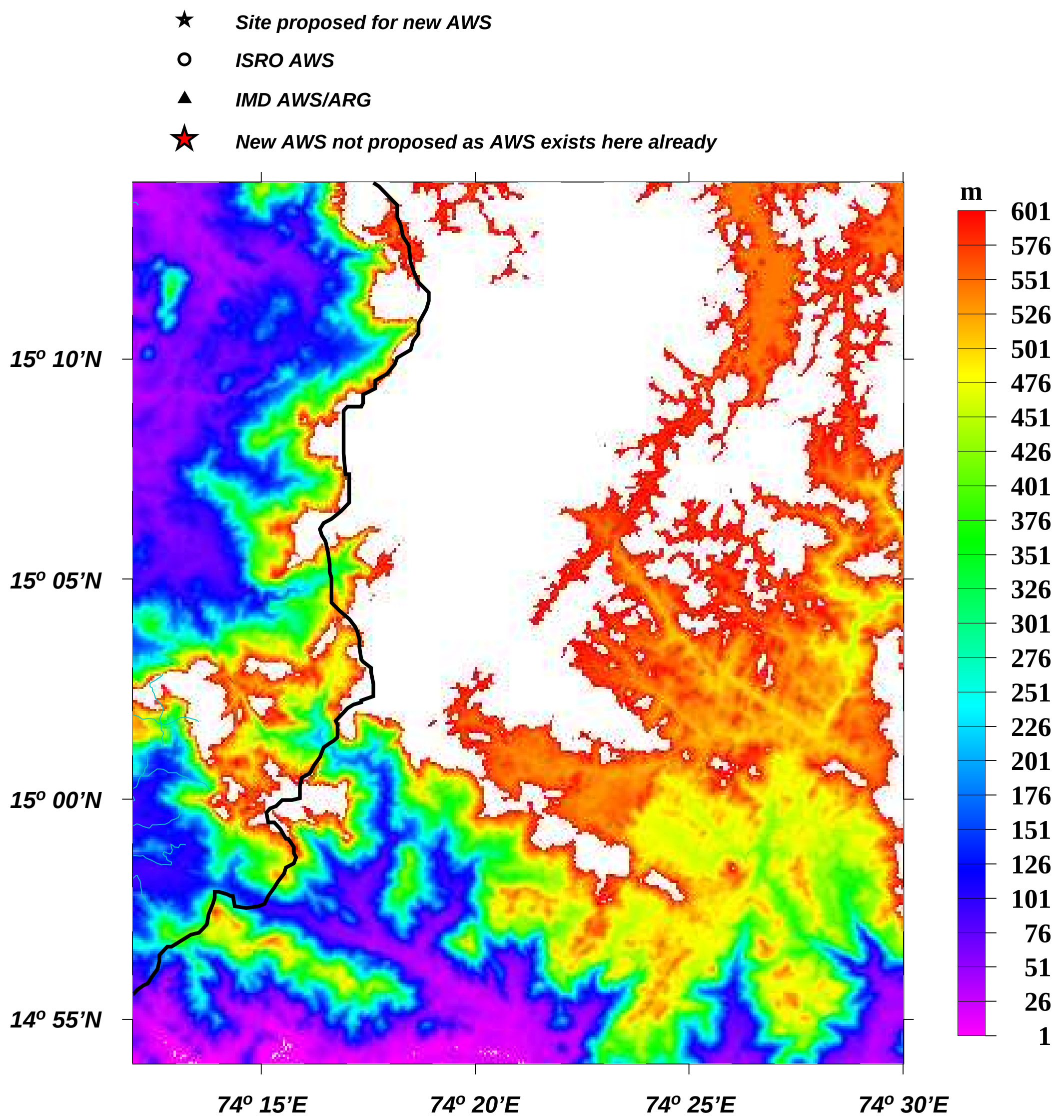

Figure 15: Same as Figure 8, but for sub-division VIII.

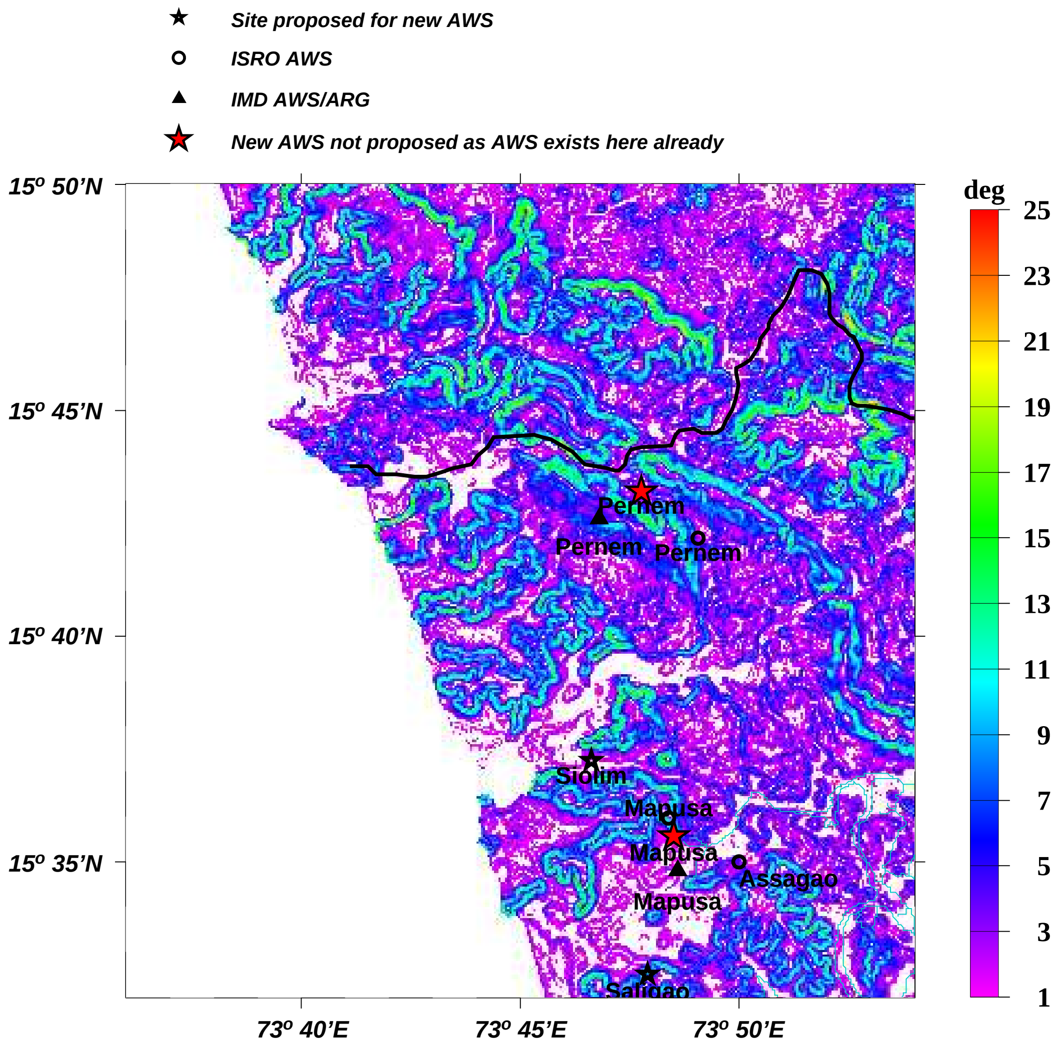

Figure 16: Same as Figure 7, but for subdivision I. The locations of the existing IMD and ISRO Automatic Gauges and the proposed sites for the new Automatic Weather Observing Systems are superimposed with different symbols.

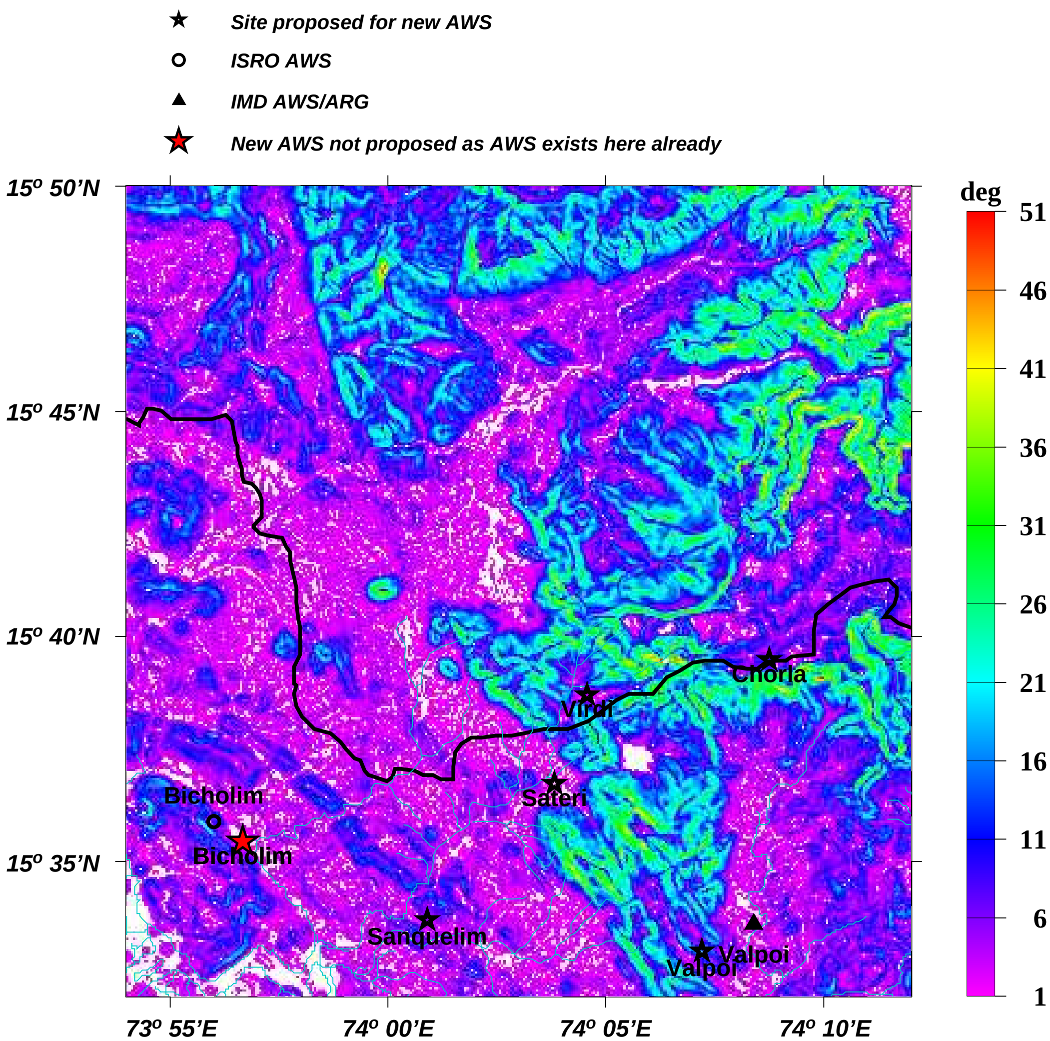

Figure 17: Same as Figure 16, but for the landscape of Sub-division II alone, to have a magnified image of the terrain.

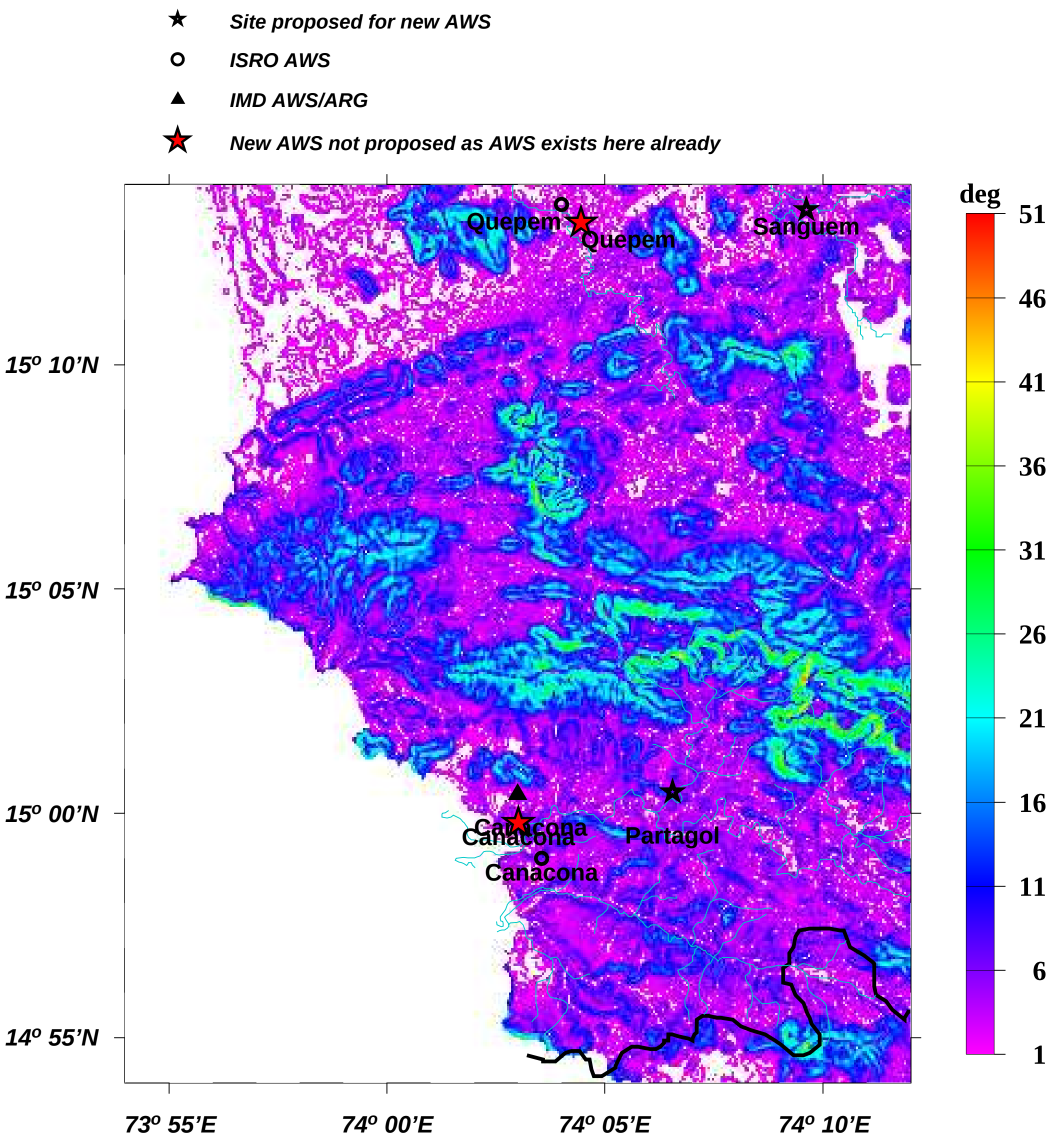

Figure 18: Same as Figure 16, but for subdivision VIII.

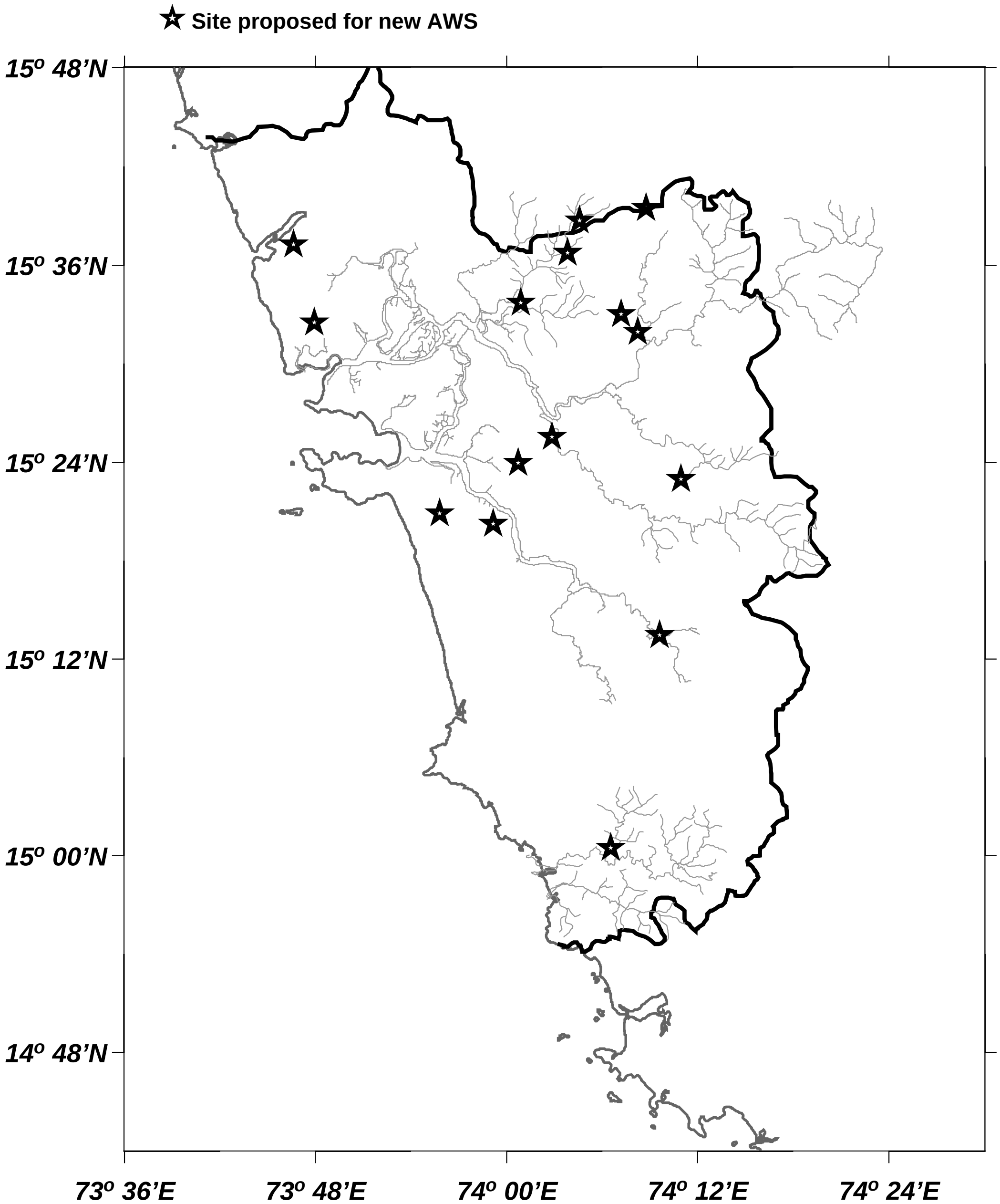

Figure 19: Locations of the proposed sites for the installation of new Automatic Weather Observing Systems.

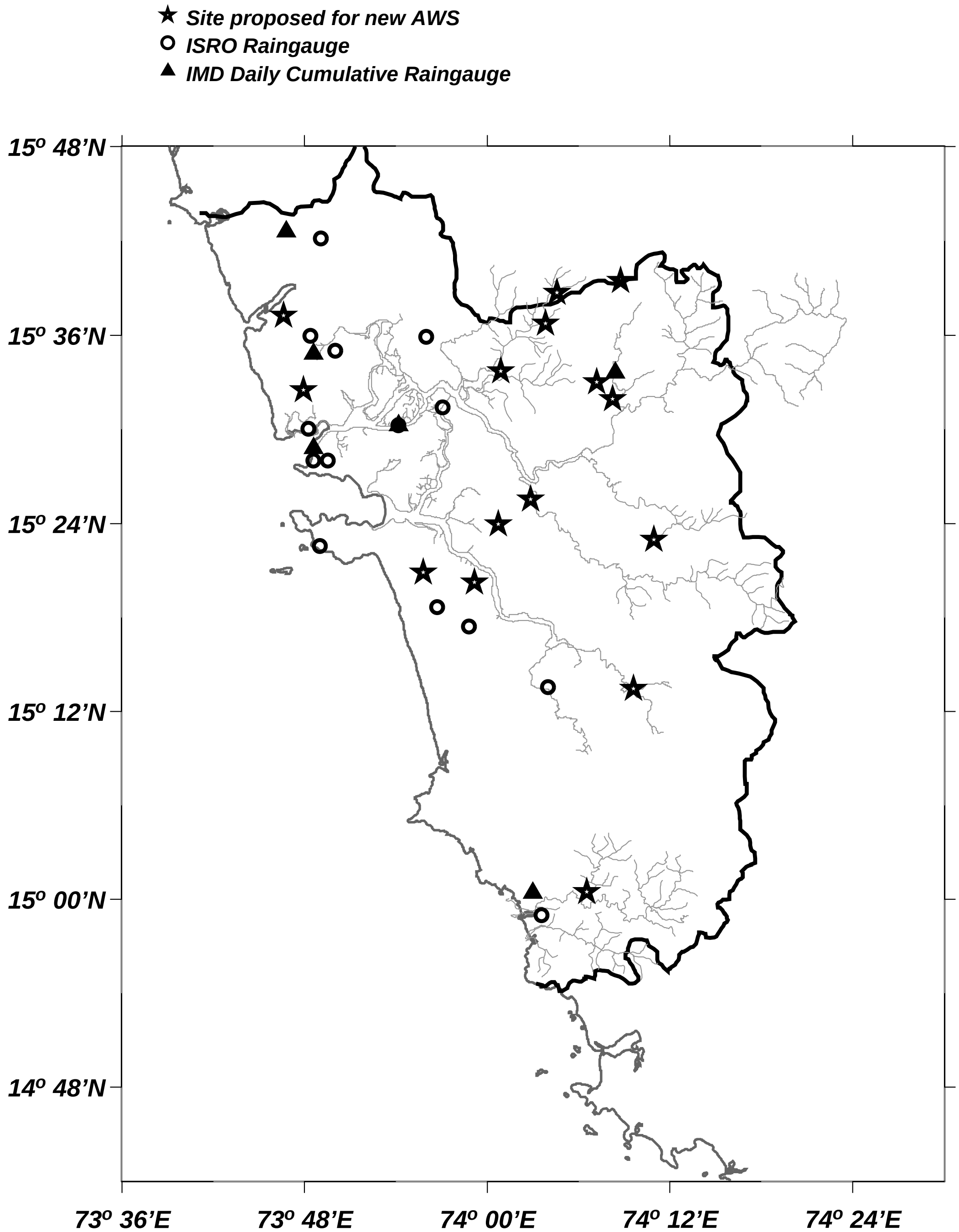

Figure 20: The final layout of the network of the Automatic Weather Observing Stations is also shown. This network includes the existing IMD and ISRO gauges and the proposed new gauges.