Improved Estimation of TV White Spaces in India using Terrain Data

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***Abstract*—Cognitive radio offers a novel solution to overcome the problem of spectrum underutilization by providing spectral access to secondary users. The television (TV) bands are of particular interest for secondary usage due to their high penetration power and greater coverage. These licensed bands are occupied only in few regions while in most of the other regions they are unoccupied and are termed as *TV white space* (TVWS). The estimation of TVWS has mostly been done by using the statistical and empirical propagation models. In this paper, terrain data is incorporated into the estimation of TVWS and shown to improve the quantitative estimation of TVWS. Using the relevant transmitter information and terrain data in the Indian state of Telangana, the efficacy of the proposed approach is demonstrated. The performance of the proposed approach is compared to that of widely used Hata propagation model. It is shown that the accuracy in TV coverage estimation increases on an average by 45% while incorporating terrain data as compared to using only empirical propagation model. As area outside the TV coverage is TVWS, the increased accuracy in the estimation of TV coverage directly translates to improved accuracy in the estimation of TVWS, which in turn translates into more efficient use of spectrum and better interference management.**

Keywords*—Cognitive Radio, Propagation Models, Signal Estimation, Terrain Model, White Spaces.

I. INTRODUCTION

Cognitive radio offers a novel solution to overcome the spectrum underutilization problem by allowing an opportunistic secondary usage of the spectrum resources along with highly reliable communication [1]. Among all the unutilized portions of the frequency spectrum that are available for secondary access, the very high frequency (VHF) and ultra high frequency (UHF) television (TV) bands have been of particular interest due to their propagation characteristics as compared to the higher frequency bands. The spatial regions where the TV bands are unutilized are called TV white spaces (TVWS). These TVWSs can be used for secondary purposes without causing any interference to the performance of the TV broadcasting in the remaining areas [2], [3].

Secondary access to TVWS involves detection of the unutilized spectrum in a given region on TV frequencies and to use the spectrum based on the regulatory requirements. This detection of TVWS can be done in two ways: *spectrum sensing* and *geolocation database*. In spectrum sensing, the secondary devices sense the power levels of the potential channel based on the regulatory requirements. In geolocation database, the white space devices consult a centralized geolocation database to determine if there are any free channels that can be used without causing interference to other services. This information can be obtained at the database using a propagation model and the known transmission parameters of the TV signals. The geolocation database approach is attractive for TVWS estimation as TV transmitters are static and use only a fixed set of frequency bands for their transmission. Another advantage is that no spectrum sensing is needed at the white space devices that may be mobile and have limited computational capabilities. However, the decision whether to declare a given location as TVWS is highly dependent on the radio propagation model employed for the construction of the geolocation database. Motivated by this concern in this paper we compare different propagation models for geolocation based TVWS estimation and illustrate our findings using actual data from the state of Telangana in India.

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In the literature, TVWS estimation has been carried out in many places around the world. For example, in USA [4], in India [5], and in Finland [6], [7]. However, most of these are based on propagation models which do not consider the terrain data. While simple propagation models are attractive from computational point of view, they often lack in accuracy and tend to either under or overestimate the amount of TVWS. In this paper, we develop an approach to estimate TVWS in India incorporating the terrain data using the ITU-R P 1546.4 model, which was not considered in previous research works so far. The performance of the terrain based approach is compared with that of widely used empirical propagation model of Hata. Although it is intuitive that terrain data should improve the accuracy of TVWS estimation as compared to the empirical model, quantification of such results in a real environment is important. Noting that the region outside the TV coverage is defined as TVWS, we quantify the accuracy in the coverage estimation of TV transmitters in the state of Telangana in India for the two propagation models. It is shown in this paper that the difference in the coverage estimation between the proposed model based on terrain data and Hata models can be as much as 45% on average. To this end, the location and transmission parameters of 34 TV transmitters in the state of Telangana together with the relevant terrain data have been obtained. Our method can be easily extended to the whole of India provided that the necessary information about the TV transmitters is available for the entire country.

This paper is organized as follows. In Section II, propagation models relevant to this paper are briefly presented. Section III details the methodology undertaken to evaluate the coverage of TV transmitters. Results are presented in Section IV followed by conclusion in Section V.

II. PROPAGATION MODELS

In wireless communications when a signal propagates from transmitter to the receiver, the power of the signal is affected by distance, terrain, obstructions (such as trees, buildings etc.), and atmospheric conditions. In this paper, two different propagation models are used to estimate the TVWS: *Hata* and *ITU-R P 1546*. These propagation models are explained in the following subsections.

A. Hata model

Hata model (also known as Okumura-Hata model) is one of the most widely used propagation models for signal prediction in urban scenarios. The simplified path loss equations have been derived from empirical measurement results. This model takes parameters such as transmission frequency (f_c in MHz), transmitter height (h_b in m), receiver height (h_m in m), distance (d in km), and different environments (such as urban, suburban, rural). This model is applicable over frequencies of 150-1500 MHz, effective transmitter heights of 30-200 m, effective receiver height of 1-10 m, and distances of 1-20 km [8]. Therefore, this model is suitable for TVWS and has been used in the TVWS literature [5], [9].

The standard form for empirical path loss in dB is given in [8] by

$$P_L = A + B\log(d) + C \tag{1}$$

where

$$\begin{aligned} A &= 69.55 + 26.16\log(f_c) - 13.82\log(h_b) - a(h_m) \\ B &= 44.9 - 6.55\log(h_b) \end{aligned}$$

where the parameters C and $a(h_m)$ depend on the environments. For small, medium, and metropolitan cities, $C = 0$. For suburban environments, we have

$$C = -2[\log(f_c/28)]^2 - 5.4$$

and for rural area it is

$$C = -4.78[\log(f_c)]^2 + 18.33\log(f - c) - 40.98.$$

The function $a(h_m)$ for metropolitan areas is given by

$$a(h_m) = \begin{cases} 8.29(\log(1.54h_m)^2 - 1.1) & \text{for} \quad f_c \leq 200\text{MHz} \\ 3.2(\log(11.75h_m)^2 - 4.97) & \text{for} \quad f_c > 200\text{MHz} \end{cases}$$

whereas for other environments it is given by

$$a(h_m) = (1.1\log(f_c) - 0.7)h_m - (1.56\log(f_c) - 0.8).$$

B. ITU model

In this paper, the terrain-based propagation model chosen is ITU-R P.1546.4 path loss prediction recommendation [10] together with the corresponding terrain data. This model is suitable for our purpose as this recommendation is primarily intended for use with broadcasting and mobile services where the transmitter/base antenna is above the level of local clutter. This recommendation is an empirical prediction method for point-to-area radio propagation for terrestrial radio transmission in the 30 to 3000 MHz frequency range. It can be used for predicting path losses over land paths, sea paths, and mixed land–sea paths. The model is valid for distances of 1 to 1000 km and effective transmit antenna heights below 3000 m. The recommendation includes corrections to account for terrain clearance and terminal clutter obstructions. However, the predicted values used here do not include shadowing caused by objects not related to terrain data such as buildings or other man-made constructions. However, there are methods for taking such factors into account when accurate infrastructure data can be provided. The resolution for the terrain data is 30 m × 30 m. It is assumed that the measurements are done with the receiver height of 3.5 m.

The ITU recommendation is empirically derived from measurement data and is represented as field strength curves (in dB ($\mu V/m$)) as a function of distance d (in km) for a given set of antenna heights, frequencies, and percentage time. For example, Fig. 1 shows field strength plotted against distance d over the range of 1 km to 1000 km for different antenna heights. These curves are for transmitter frequency of 600 MHz and assuming only land path between transmitter and receiver. Similar curves for other nominal frequencies, transmitter heights, and terrains are available in the recommendation. All curves assume 1 kW effective radiated power. Nominal frequencies are 100, 600, and 2000 MHz while nominal antenna heights are 10, 20, 37.5, 75, 150, 300, 600, and 1200 m. Nominal terrain paths are land, sea, or/and mixed. Since the state of Telangana (our test region) is a land-locked state, we will only focus on the measurements based on a land path.

The estimate of field strength are then obtained for other values of antenna heights, frequencies, and percentage time by interpolation and extrapolation of the measurement data under different geographical and climatic conditions. For example, field strength propagation curves for 1 kW effective radiated power at nominal frequencies of 100, 600, and 2000 MHz as a function of different parameters are used to extrapolate or interpolate field strengths at other frequencies. Although propagation conditions may vary according to the weather conditions, the methods for interpolation and extrapolation between families of field-strength curves are general.

1) Interpolation of field strength as a function of distance d: No interpolation for distance is needed if field strength is directly read from the graphs like Fig. 1. Otherwise, the field strength, E in dB ($\mu V/m$)), should be linearly interpolated for the logarithm of the distance [10] using

$$E(d) = E_{inf} + \frac{(E_{sup} - E_{inf})\log\frac{d}{d_{inf}}}{\log\frac{d_{sup}}{d_{inf}}} \tag{2}$$

where,
d : distance for which the prediction is required
d_{inf} : nearest tabulation distance less than d
d_{sup} : nearest tabulation distance greater than d
E_{inf} : field-strength value for d_{inf}
E_{sup} : field-strength value for d_{sup}

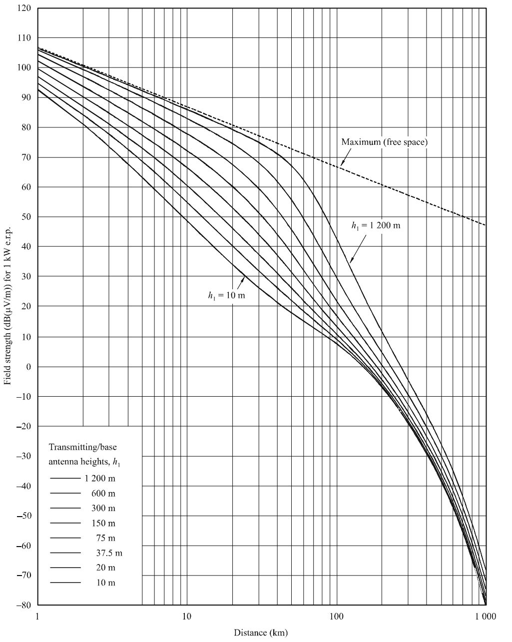

Fig. 1. Curves for field strength as a function of distance for different transmitter heights. These curves are for transmitter frequency of 600 MHz and assuming only land path between transmitter and receiver [10].

2) Interpolation as a function of antenna height, h_1: As can be seen from Fig. 1, the field strength versus distance curves given in the recommendation are for transmitter antenna heights of 10, 20, 37.5, 75, 150, 300, 600, and 1200 in meters. If the value of h_1 coincides with one of the eight heights for which curves are provided, the required field strength may be obtained directly from the plotted curves or the associated tabulations. Otherwise, the required field strength should be interpolated or extrapolated from field strengths obtained from two curves using [10]

$$E(h_1) = E_{inf} + \frac{(E_{sup} - E_{inf}) \log \frac{h_1}{h_{inf}}}{\log \frac{h_{sup}}{h_{inf}}} \tag{3}$$

where,
$h_{inf} = 600$ m if $h_1 > 1200$ m, otherwise the nearest nominal effective height below h_1
$h_{sup} = 1200$ m if $h_1 > 1200$ m, otherwise the nearest nominal effective height above h_1
E_{inf} : field-strength value for h_{inf} at the required distance
E_{sup} : field-strength value for h_{sup} at the required distance
This recommendation is not valid for $h_1 > 3000$ m.

The transmitting/base antenna height, h_1, to be used in calculation depends on the type and length of the path and on various items of height information, which may or may not all be available. When the terrain information is available as in our case, it is given by

$$h_1 = \begin{cases} h_b & \text{for land paths shorter than 15 km} \\ h_e & \text{for land paths of 15 km and longer} \end{cases}$$

where h_b is the height of antenna above terrain height averaged between $0.2d$ and d km while h_e is the height of antenna above terrain height averaged between 3 and 15 km.

3) Interpolation and extrapolation of field strength as a function of frequency: Field-strength values for the required frequency should be obtained by interpolating between the values for the nominal frequency values of 100, 600, and 2000 MHz. In the case of frequencies below 100 MHz or above 2000 MHz, the interpolation must be replaced by an extrapolation from the two nearer nominal frequency values. The required field strength should be calculated using [10]

$$E(f) = E_{inf} + \frac{(E_{sup} - E_{inf}) \log \frac{f}{f_{inf}}}{\log \frac{f_{sup}}{f_{inf}}} \tag{4}$$

where,
f : frequency for which the prediction is required (MHz)
f_{inf} : lower nominal frequency (100 MHz if $f < 600$ MHz, 600 MHz otherwise)
f_{sup} : higher nominal frequency (600 MHz if $f < 600$ MHz, 2000 MHz otherwise)
E_{inf} : field-strength value for f_{inf}
E_{sup} : field-strength value for f_{sup}

III. METHODOLOGY

A. TV Transmission parameters

Coverage area computation has been done for total 34 transmitters (28-VHF and 6-UHF) falling under four Doordarshan Maintenance Centers (DMCs) in the state of Telangana. The transmitter parameters that have been obtained from these DMCs for calculating the TV coverage area are [1]:

- Location of the transmitter (latitude and longitude)
- Transmission power of the TV transmitter
- Channels of operation and their center frequency
- Height of the antenna above ground level.

B. Terrain Data

There are various ways of representing continuous surfaces in digital form using a finite amount of storage. In this paper, we have used digital elevation model (DEM) which is one of the simplest and widely used models for the digital representation of topographical information. Most often it is used to refer a raster or a grid of spot heights. The resolution of DEM is the distance between the adjacent grid points, which is a critical parameter. DEM covers the entire globe and can be obtained at various resolutions.

The DEM for this work has been obtained from National Remote Sensing Centre (NRSC) which provides terrain information with 30-meter resolution [11]. Fig. 2 represents the

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[1] The TV tower data is not available publicly in India. We could obtain the data with considerable efforts from Doordarshan. Hence,the parameters are confidential and are not included in this paper

DEM for a region in the Telangana State. The light color regions observed in the figure correspond to low elevation regions and the dark colored regions correspond to high elevation regions.

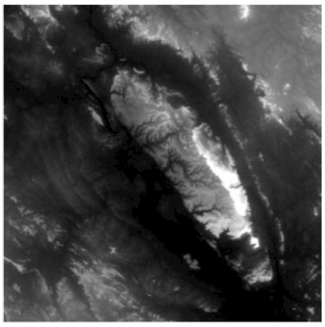


Fig. 2. Digital elevation model (DEM) for a region in the state of Telangana.

C. Coverage area and TVWS computation

Using the above parameters, signal estimates for each pixel (smallest unit of geographical coverage) for the two propagation models described in the earlier section: Okumura-Hata and ITU. The receiver height $h_m = 3.5$ m is assumed. For successful reception of TV signal, the minimum required SNR is $\Delta = 15$ dB while noise power in 8 MHz bandwidth is $N_0 = -104.97$ dBm and fading margin $F_A = 1$ dB [5]. Therefore, a pixel or location at a distance d from the transmitter is inside a coverage region if the SNR at the receiver exceeds Δ after accounting for expected fading, i.e.,

$$P_t - P_L(d) - F_A - N_0 \geq \Delta \tag{5}$$

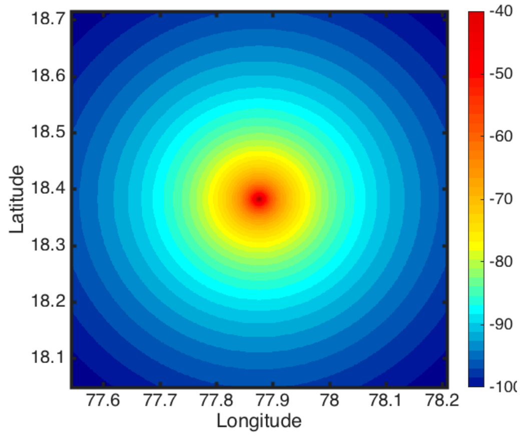
where P_t is the transmission power and $P_L(d)$ is the path loss from the Hata-model or the ITU-model. Note that the area outside the coverage region is the TVWS for that particular transmitter.

IV. RESULTS

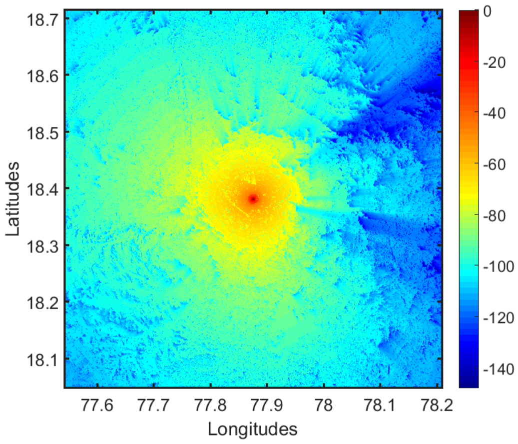
In this section, results are presented in three stages. In the first stage, the signal strength estimation results are presented for the two models for the considered scenarios. In the second stage, the coverage region for a given transmitter is evaluated for the two channel models. Let these coverage regions be denoted by C_H, and C_{ITU} for Hata and ITU models respectively. In the third stage, we evaluate the relative error in Hata model with respect to the ITU model. In both the stages, we start with an example of the transmitter located at Banswada to explain the procedure for the proposed approach. The same procedure has been followed for other transmitters as well for the last two stages.

A. Signal strength estimation

To effectively represent how the signal power decays with distance, a color map of received power (in dB) is plotted w.r.t. latitude and longitude for the two channel models as shown in Fig. 3. As it can be seen that the color near the center of the box is more reddish to indicate high received power (-30 dB to -60 dB) because of its shorter distance from the transmitter.



(a) Hata



(b) ITU

Fig. 3. Estimated signal strength in dB for considered scenario for the three propagation models: (a) Hata (b) ITU.

Moreover, the effect of terrain data incorporation can be clearly seen as the estimated signal strengths changes with terrain and direction for ITU model, unlike the Hata model which has circular contours for a given signal strength.

B. Estimation of TV coverage

Fig. 4 shows the comparison of the coverage regions for Hata and ITU models. It can be observed from the figure that towards the border regions, there is heavy mismatch in the coverage region. Table I shows the estimated coverage in km^2 for the two channel models, i.e., C_H, and C_{ITU} corresponding to the 34 TV transmitters in the state of Telangana. From the table, it can be observed that for some TV transmitters (e.g., Banswada, Hyderabad, etc.), the coverage for Hata model is more than that of ITU models. Similarly, for some TV transmitters (e.g., Devarakonda, Medak, etc.), the coverage for

ITU model is more than that of Hata. However, the estimates of the coverage areas for both the models are in the same order of magnitude.

C. *Error calculation for Hata wrt ITU*

As ITU model incorporates terrain data in addition to the propagation model, it is reasonable to assume that the ITU model will be more accurate than the Hata model. Therefore, in this subsection, we quantify the improvement in accuracy that can be obtained by incorporating the terrain data as compared to only propagation model. This quantification is done in terms of relative error for Hata model with respect to ITU model and the procedure and results are given in this subsection.

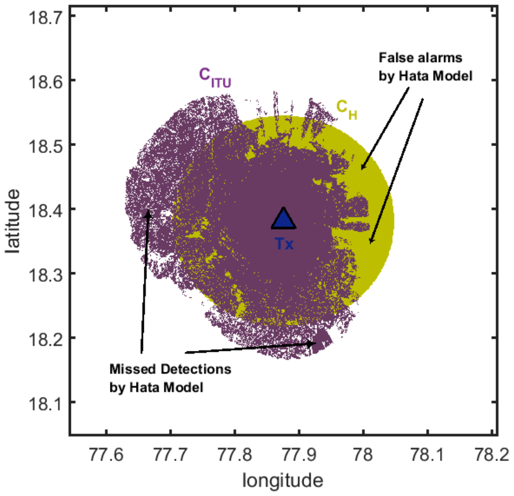


Fig. 4. Coverage for Hata and ITU models along with false alarms and missed detections for Hata model with respect to ITU model.

Fig. 4 also shows that near the border regions, there is heavy mismatch in the estimated coverage region using Hata and ITU models. It is assumed that a false alarm has been raised by Hata model at a location if Hata model declares the location to be occupied but ITU-R declares it to be free. Similarly, a missed detection is said to occur by Hata model at a location if Hata model declares the location to be free but ITU-R declares it to be occupied. False alarm results in a false belief that spectrum is occupied by a primary user and thus results in inefficient spectrum reuse. On the other hand, missed detection results in a false belief that the spectrum is free while a primary user is still there. This may result in interference to the primary user which must be avoided as much as possible. Thus, errors in the coverage estimation lead to errors in TVWS estimation and consequently in inefficient use of spectrum.

Let E_{fa} be the total area where false alarms have occurred while E_{md} to be total area where missed detections have occurred. The total area where Hata model is making an error with respect to ITU model, denoted by E_{HI}, is then given by

$$E_{HI} = E_{fa} + E_{md} \tag{6}$$

Table I also presents the total area corresponding to different errors (missed detection, false alarm, and total error) in the coverage estimation for Hata model relative to ITU model. It can be seen that the widely used Hata model suffers from significant errors with area under errors being in hundreds of square kilometers. Thus, it can be seen that the widely used Hata model may result in too many false alarms and missed detections, which in turn, lead to highly inefficient spectrum reuse in cognitive radio networks. Using terrain data on the other hand, as proposed in this paper, demonstrates and quantifies the improvement in the estimation of coverage and subsequently TVWS.

Different TV transmitters have different coverage areas based on their transmission parameters such as frequency, antenna height, and transmitted power. This is visible from Table I as a variation in the estimated coverages (in km^2) for different transmitters. Similarly, there is lot of variation in the total error (in km^2) while estimating the coverage regions of different transmitters using the Hata model. For making these total errors comparable for different transmitters, we use relative error which is the total error normalized by the coverage of Hata model, i.e.,

$$R_E = \frac{E_{HI}}{C_H} \times 100\ \% \tag{7}$$

The last column in Table I shows the R_E for various transmitters in Telangana. It can be seen from this last column that the relative error in TVWS varies for different transmitters since ITU model results in different coverage regions for different transmitters based on the terrain. The relative error ranges between 25% to 70% with the average error being 45% which is significant.

V. CONCLUSION

This paper focused on demonstrating and quantifying the improvement in accuracy of TVWS obtained by using the terrain data in the empirical propagation models. ITU-R P1546.4 model is used for this purpose which considers the terrain along with propagation models. The performance of the proposed approach is compared to that of the widely used Hata model which is a deterministic and empirical channel model. The coverage estimation for the two models is carried out for all the TV transmitters in the state of Telangana. The results are evaluated using actual TV transmission parameters obtained from Doordarshan and the terrain data obtained from NRSC. It is shown that the relative accuracy in the estimation of TV coverage increases on an average by 45% while incorporating terrain data as compared to using only propagation models. This clearly demonstrates a significant increase in the accuracy of TV coverage estimation and consequently in TVWS estimation by using ITU model instead of Hata model.

ACKNOWLEDGMENT

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TABLE I. ESTIMATED COVERAGE FOR THE TRANSMITTERS IN THE STATE OF TELANGANA USING HATA AND ITU MODELS AND ALSO THE ABSOLUTE AND RELATIVE ERRORS IN HATA MODEL AS COMPARED TO ITU MODEL.

S.No:	Location Name	Coverage area [HATA] (C_H) in Km^2	Coverage area [ITU-Terrain] (C_{ITU}) in Km^2	Missed detection (E_{md}) in Km^2	False alarm (E_{fa}) in Km^2	Total Error ($E_{md}+E_{fa}$) in Km^2	% of Error
1	Banswada	1042.20	971.51	224.63	295.30	519.93	49.89%
2	Hyderabad	3402.59	2077.24	26.31	1351.74	1378.05	40.50%
3	Devarakonda	1166.95	1309.91	280.74	137.74	418.48	35.86%
4	Medak	1174.48	1339.52	311.16	146.12	457.27	38.93%
5	Siddipeet	1040.98	1123.16	235.87	153.68	389.55	37.42%
6	Nizamabad	680.76	701.09	169.96	149.63	319.59	46.95%
7	Nalgonda	2548.42	2315.12	249.08	482.31	731.39	28.70%
8	Miryalaguda	574.50	670.90	143.70	47.29	190.99	33.24%
9	Madgula	532.09	585.79	113.79	60.09	173.88	32.68%
10	Kamareddy	982.98	1071.56	248.54	159.97	408.51	41.56%
11	Adilabad	1049.69	1137.38	310.44	222.75	533.19	50.79%
12	Bhainsa	1261.34	1442.29	333.60	152.73	486.33	38.56%
13	Nirmal	1182.01	1181.58	260.76	261.16	521.91	44.15%
14	Jagital	426.96	426.93	114.70	114.71	229.41	53.73%
15	Karimnagar	3052.29	2712.37	187.00	526.95	713.95	23.39%
16	Vemulawada	572.57	739.89	235.47	68.17	303.64	53.03%
17	Siricilla	930.41	996.28	223.20	157.29	380.49	40.90%
18	Ballempally	934.30	1063.87	296.94	167.37	464.31	49.70%
19	Bhadrachalam	979.75	1335.89	465.58	109.44	575.02	58.69%
20	Khammam	3224.45	3185.54	361.24	400.15	761.39	23.61%
21	Kothagudem	3446.31	2220.83	76.19	1301.67	1377.86	39.98%
22	Pedapalli	867.50	1288.86	506.55	100.15	606.70	69.94%
23	Ramagundam	1044.41	1275.32	379.05	148.13	527.18	50.48%
24	Sirpur Khagaznagar	1183.25	1103.04	266.57	346.78	613.35	51.84%
25	Yellandu	925.80	866.82	217.80	276.78	494.58	53.42%
26	Mahabubnagar	984.66	675.35	143.87	453.18	597.05	60.64%
27	Jadcherla	922.43	1401.87	574.00	94.56	668.56	72.48%
28	Kosgi	1009.26	1194.11	319.15	134.29	453.44	44.93%
29	Nagarkurnool	1242.51	1193.80	171.04	219.74	390.79	31.45%
30	Narayanpet	411.29	444.63	159.29	125.96	285.25	69.35%
31	Talakondapalli	478.41	521.64	127.50	84.27	211.77	44.26%
32	Veldanda	411.38	565.08	216.35	62.64	278.99	67.82%
33	Wanaparthy	1030.51	1363.58	482.57	149.50	632.07	61.34%
34	Achampet	1093.83	1343.36	455.10	205.56	660.66	60.40%

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