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The Problem of Ghosting in Television Signal Reception in Mountainous Areas, Idanre in Western Nigeria as a Case Study

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Abstract

Television signals may reach the TV receiver by a longer path after reflection from a large object such as huge buildings, hills, trees, etc., which creates undesirable poor quality reception and noise. This unwanted signal arrives a little later than the desired signal reaching directly and produces another image on TV receivers slightly displaced horizontally from the desired image. This displacement is proportional to the line delay between the two paths.

This paper focuses on the problems encountered by the reception in such an irregular terrain where signal is obstructed by hills and the way of minimizing this to a bearable level using narrow beamwidth, high directivity and high gain antenna. From the results obtained it could be observed that the signal received is a superposition of both direct and reflected signals which resulted into multiple images due to the impact of the obstacles. The ghost picture has much contrast than the main picture since the ghost signal is weak. If the path difference is small, no separate ghost picture may appear but the main picture may simply appear fuzzy. This implies that obstacles (hills) on a transmission path have much effect on the reception of television signals.

***Keywords**: Ghosting, television signal reception, irregular terrain, reflection, diffraction, fading and multipath.*

Introduction

'Ghosting' is the effect one sees when several identical images seem to be superimposed on each other. This is a sign that the signal is arriving at the antenna from two or more directions at the same time, because the original signal has been reflected randomly off local buildings, trees (Head 1960) and terrain (Furutsu 1959). The technical term for this is 'multipath'. If the images one sees superimposed on each other are different, it means that the TV is picking up signals from other channels, which is called 'co-channel interference'.

The second zone of potential interference is produced by reflection or scattering of the incident signal. Even though television signals travel at the speed of light, the different path lengths can mean that one signal arrives with a significant delay relative to the other.

The path diversity results in a second image appearing on the viewer's screen displaced from the first one. This type of interference is known as 'delayed image' or, 'ghosting'. If the reflected signals are more complex, several such ghost images can be seen (Millington, *et al*. 1962).

The general location of the 'reflection' zone depends on the angle of the incoming signal and the orientation of the hills. The extent of the zone and degree of interference within the zone depend on the relative strengths of the direct signal and the reflected signal, determined by the radio-frequency reflectivity of the hills, and also on the delay between the

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two signals. The greater the relative strength of the reflected signal, and the longer the delay, the more subjectively intrusive this problem becomes.

If ghosting is caused by a single structure that creates one distinct ghost image, a medium or large multi-directional antenna with careful positioning may be useful to eliminate the reflected signal. However, the antenna may require different positioning for each channel. Directional antennas are the most ghost-resistant antennas since they 'see' in only one direction and have a tendency not to 'see' the reflected ghost signal. The further away from structures the antenna is located, the less likely a problem will occur. Many factors, however, such as the structure's total surface area, the direction it faces, and neighborhood terrain will influence how much effect the structure will have on TV reception.

Another factor which significantly affects the size and shape of the 'scattered' or 'reflected' interference zone is the radiation pattern of the viewer's receiving antenna. Consider a location where the delayed signal has relative amplitude and delay consistent with unacceptable interference. If the angle between the source of the direct signal and the source of the delayed signal is greater than about 45^{o}, an antenna whose pointing is optimized to receive the direct signal will discriminate against the delayed signal. For critical applications, a very narrow beamwidth aerial may be used to reduce the strengths of delayed images to acceptable levels (Saxton and Lane 1955).

Propagation by Diffraction

The field strength due to diffraction is caused by radiation of currents induced by the incident field. The study of diffraction is very difficult especially for obstacles, which do not have a geometrically simple shape. Only two theoretical cases have been studied in detail: diffraction by a large radius sphere and diffraction by a ridge of low or negligible thickness. Practical problems are reduced to combinations of these two theoretical cases (Bothias 1987).

Consider a ridge of zero thickness at the summit, which is at height h (positive or negative) with respect to the straight line between the transmitter, T and the receiver, R, as shown in Fig. 1.

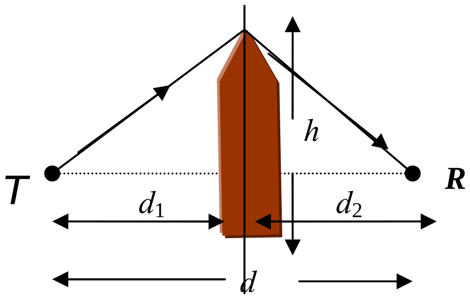

Fig. 1. Knife-edge diffracting ridge.

Let d be the total distance, d_1 and d_2 be the distances from the ridge to the transmitter and to the receiver, respectively, and λ be the wavelength. If the angle of diffraction is assumed small and introducing a variable v, such that

$$v = h\sqrt{\left(\frac{2}{\lambda}\right)\left(\frac{d}{d_1 d_2}\right)}, \qquad (1)$$

an approximation for the ratio of corresponding powers, which is valid for $v > -0.7$ is

$$10\log\left(\frac{P}{P_0}\right)$$
$$= -6.9 + 20\log\left[\sqrt{(v-0.1)^2+1} - v + 0.1\right], \qquad (2)$$

where P_0 is the received power without the ridge and P is the power received with the ridge.

The waves which radiate away from the TV station's transmitting antennas travel most easily in dry air and in paths that are very close to a straight line. Even in dry air they do gradually become weaker with the distance, because of the way they are steadily spreading out as they radiate away. But providing there's a reasonably clear line of sight between the receiving antenna and the transmitter tower and the receiver is not more than 30 km from the transmitter, there should still likely to be a signal strong enough for good reception in most conditions with high gain outdoor antenna.

Received Signal at the Location

The direct and reflected signals received by the receiving antenna which result in multiple ghosting could be represented by the well known plane wave solution in one dimension as given below:

$$\varphi(x,t) = s(x,t)e^{j\omega_c\left(t - x/c\right)}, \qquad (3)$$

where $s(x,t)$ is the information bearing (or complex envelope) of the wave propagation in the x direction and the carrier frequency in radian/sec. Having the delay = x/c and making the spatial dependency x implicit one can have:

$$\varphi(t,\tau) = \left[s(t-\tau)e^{-j\omega_c\tau}\right]e^{j\omega_c t}. \qquad (4)$$

In a multipath environment, $r(t)$, the complex low-pass representation of the received signal is the contribution of many rays:

$$r(t) = \sum_n \alpha_n(t)s(t - \tau_n(t))e - j\omega_c\tau_n(t), \qquad (5)$$

where $\alpha_n(t)$ denotes the time varying complex amplitude of the n^{th} ray. Note that in addition to the time varying amplitude $\alpha_n(t)$, the delay of each path is also a function of the time. Equivalently, the RF equivalent counterparts of $r(t)$ and $s(t)$ denoted by $S(t)$ and $R(t)$ are:

$$S(t) = \mathrm{Re}\left\{s(t)e^{j\omega_c t}\right\},$$

$$R(t) = \Re\left\{\sum_n (t)S(t - \tau_n(t))e^{j\omega_c(t - \tau_n(t))}\right\}. \qquad (6)$$

The real problem of this reflection of signals is the arrival of the reflected and direct signals at the receiver at different times as in Fig. 2. Since radio waves travel in air at virtually the same speed, c, as the speed of light of 300,000 km/s, so the receiving antenna at a distance R km from the transmitting station receives its signals in R/c seconds. This tiny delay does become important when reflected signals from the same station can also reach the antenna, say by reflection from a hill.

The reflected signals also travel at the same speed, but clearly they are traveling along a longer path to get to the antenna. This means that they will take slightly longer time to get there, arriving just after the signal which arrives via the direct path (which is clearly the shorter path).

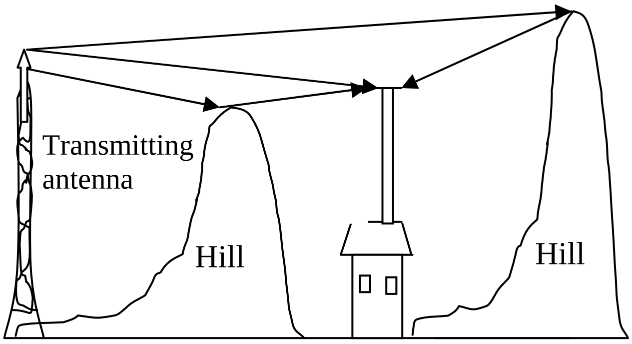

Fig. 2. The reception of direct and reflected signals that causes ghosting.

As a result, the set receives a mixture of two distinct versions of the station's signal, one always arriving r/c seconds after the other. So instead of getting just one picture on the screen, two or multiple pictures are obtained depending on the number of reflected rays trapped by the antenna, the main one (from the direct path) and weaker one(s) (from the reflected path). The weaker one(s) should be shifted to the right because of the way the TV set scans the picture lines from left to right.

The second picture was usually less distinct and more weakly colored, because it is from a weaker signal. Although the extra ghost images were fainter and more weakly colored, they were quite distracting and seriously degrade the clarity of the main picture. That is why they are regarded as a reception problem.

Hence, in analyzing the causes of ghosting in television reception, the following determinants are taken into consideration:

- The amount by which the direct ray clears terrain prominences or is blocked by them;
- The position of terrain prominences or obstacles along the path;
- The strong influence of the degree of roundness of these terrain features;
- The apparent earth flattening due to atmospheric refraction.

Even in line-of-sight conditions when all terrain prominences lie below the direct ray, some may come close enough to weaken the received field. This weakening effect is evaluated in terms of the degree to which prominence penetrates certain geometrically defined zones, called Fresnel zones, around the direct ray. The second determinant, position of the prominence or obstacle along the path, is important because the football shaped Fresnel zones are fatter and thus more deeply penetrated in the middle than at the transmitter and receiver ends.

Methodology

The measurements were carried out around ten strategic places indicated on the topographical map of the town shown in Fig. A.1 in the Appendix. These measurements were carried out between the months of January and February when there were little leafs on the trees and it was between 8.00 am and 12.00 pm each day. Series of these measurements were carried out using the appropriate field strength meter.

The Geography of the Location

Idanre lies between Akure and Ondo towns. Idanre falls within latitude 9°8’N and longitude 5°5’E of the equator and Greenwich meridian, respectively. Its eastern neighbors are the Binis via Ofosun river which serves as boundary between Ondo and Edo states. To its west are the Ondos with land demarcated at Owena river. To its south are indigenes of Siluko (of old Bendel state), Onishere (Idanre tributary) and Iikale, also of Ondo state. Akure is, however, Idanre’s neighbor to the north. The total land area is put at 619 square miles (1,584.6 km^2). The annual rainfall is put at about 70 inches, though with slight variations from year to year. Thick clouds envelope the town during Harmattan period. The humidity is more pronounced in the ancient Idanre town (Odode Idanre), whose altitude is about 1,273m above the sea level. For the most part of August and December each year, the peak of Orosun hill becomes almost invisible as haze perpetually engulfs it.

Nonetheless, between January and July, the temperature averages between 78°F and 83°F, respectively. Cool breeze reigns within this period. As such, humidity which is always very high in January is often catapulted to 80 per cent in July. Being a tropical region, the town has a large share of tall trees.

The tallest trees which are distinguishable through their individuality often reach about 45m in height; next to these are trees between 23m and 3.6m tall, branches of which extend to one another thereby forming quasi-expansive canopy; while the last and most common species of trees in this area are of hard wood. The trees in this group combine with those in other groups to form impenetrable forest.

Table A.1 in the Appendix indicates the measurements taken in the main town of Odode Idanre which is surrounded by high hills, this town could be described as a town in a valley, see Fig. A.1 in the Appendix. The signals obtained here are highly affected by mountains. The propagation here suffered reflection and diffraction which caused ghosting images during TV reception even though Idanre falls within the primary coverage area and the signal expected to be received here should be up to 60 dB (1 mV/m) around the locations.

Results

The experimental results are presented in Table A.1 in the Appendix.

The Designed Receiving Antenna

Antenna Components

The main components of an outdoor antenna are: Elements, Boom and Phasing Lines as shown in Fig. 3 (Mithal and Mittal 1964; Lee 1982).

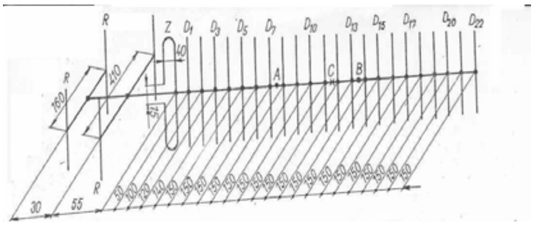

Fig. 3. The Yagi array antenna used at the receiving point.

The three elements involved are:

- **Director elements:** At the front of the antenna; smaller elements which initially pick up the signal.
- **Driven element:** The element where the coaxial cable is connected, it ‘Drives’ the signal down the coaxial cable to the TV.

- **Reflector element:** Longest element, always located at the back of the antenna, it reflects unwanted signals away and reflects the desired signal from the front of the antenna back to the driven elements.

The **Boom** is the center section the elements are fastened to. The **Phasing Lines** may be small aluminum wires or rugged aluminum braces – whatever form they are, these phasing lines pass the signal from the driven elements to the downlead coaxial cable. Sometimes, the boom will act as phasing lines, and it is called a ‘hot boom’.

Signal Strength

The broadcast signal strength at the location depends on the following variables:

1. Distance from transmitter: The farther away one is located, the weaker the signal, resulting in reduced picture and sound quality. UHF signals are harder to receive than VHF (Bullington 1947; Epstein and Peterson 1953).

With TV signals, there are two carriers in transmission – video and audio. The video (picture) will dissipate faster than audio, so the sound is received but no picture.

2. The terrain between the location and the transmitter: Unlike AM signals, which follow the curvature of the earth, TV and FM signals travel in a tangent to the earth. Other obstructions (high buildings, hills, etc.) can also interfere with broadcast signals. Interference caused by buildings and towers often causes ‘ghosting’ problems (ghosting is multiple images on the screen) – the signal from the transmitter is reflected by obstacles so that the signal reflected arrives at the TV set a split second later than the main signal from the transmitter and causes multiple imaging. A directional antenna with good side and rear rejection can eliminate or greatly reduce ghosting. Some ghosting cannot be solved without moving to another location. The size of the antenna is determined by the distance from the transmitter – antenna size, including length and number of elements, increases as distance between location and transmitter increases. In extreme fringe areas, stacking antennas (using multiple antennas on the same mast) is suggested.

Directivity and Gain of the Receiving Antenna

Often a principal goal in antenna design is to establish a specified radiation pattern in Watts per square meter through a suitable arrangement of source. The specified pattern frequently embodies the intent to enhance the radiation in certain direction and suppress it in others. A useful measure of this is the directivity, which is simply the radiated power density in the direction divided by the radiated power density average over all directions, that is:

$$D(\theta,\phi)=\frac{\xi(\theta,\phi)}{\left(1\big/4\pi r^2\right)\int^{\pi}\int_{0}^{2\pi}\xi\left(\theta,\phi'\right)r^2 Sin\theta d\theta d\phi}\,. \quad (7)$$

Equation (7) contains the implications that the origin for spherical coordinate has been chosen somewhere in the immediate vicinity of the antenna, and that power densities are being evaluated on the surface of a sphere whose radius r is large enough to ensure being in the far field of the antenna. If the radiation intensity is defined by

$$P(\theta,\phi)=r^2\xi(\theta,\phi)\,, \quad (8)$$

then, since $\xi(\theta,\phi)$ is measured in watts per square meter, it follows that $P(\theta,\phi)$ is measured in watts per steradian (steradian is the Standard International (SI) unit of solid angular measure). Substitute in Eq. (7) gives the equivalent expression:

$$D(\theta,\phi)=\frac{4\pi P(\theta,\phi)}{\int_0^{\pi}\int_0^{2\pi}p(\theta,\phi)\sin\theta d\theta d\phi}\,. \quad (9)$$

The value $D(\theta,\phi)$ is a pure numeric. It will have a value less than unity in direction in which radiation has been suppressed, and a value exceeding unity where the radiation has been enhanced. If (θ_0,ϕ_0) is the direction in which the radiation intensity is greatest, then D has its largest value at (θ_0,ϕ_0) and (θ_0,ϕ_0) is the peak directivity.

Directivity is used to compare the radian intensity in a given direction to the average radiation intensity and thus pays no heed to the power losses in the materials comprising the antenna. Gain includes these losses and the definition of gain is therefore,

$$G(\theta,\phi)=\frac{\xi(\theta,\phi)}{P_{acc}/4\pi r^{2}}\,, \tag{10}$$

in which P_{acc} is the total power accepted by the antenna from the transmitter, measured in Watts.

The gain and directivity differ by a multiplicative factor that is independent of direction. In particular, the peak gain occurs in the same direction (θ_0,ϕ_0) as the peak directivity.

Often, gain and directivity are expressed in decibels (dB),

$$\log_{10} G(\theta,\phi)=\log_{10} D(\theta,\phi)-\log_{10} K_L\,, \tag{11}$$

where K_L is a pure real constant that has a value somewhat greater than unity.

The gain in any direction is seen to be $10\log_{10}K_L$ decibels below the directivity in that direction, $10\log_{10}K_L$ thus represents the power losses in the materials forming the antenna.

Antenna Cross-Section

A receiving antenna will absorb energy from an incident plane wave and feed it via a transmission line to its terminating impedance. A useful measure of its ability to do this would result from introducing the concept of the absorption cross section of the antenna or as it is more commonly known, its equivalent receiving cross sectional area. If S is the power density of the incoming plane wave in Watts per square meter and P_r is the absorbed power in Watts, then the equation,

$$P_r(\theta,\phi)=SA_r(\theta,\phi)\,, \tag{12}$$

serves to define the receiving cross-section, in square meters, as a function of the angle of arrival of the incoming signal. In order to have $A_r(\theta,\phi)$ as a maximum measure of the capture property of the antenna, it is customary to assume that the incoming plane wave is polarization matched to the antenna, and that the antenna is terminated by a matched receiver,

$$SA_r(\theta,\phi)=\frac{1}{2}\left|I^{b},(\theta,\phi)\right|^{2}R_{RV}$$

$$=P^{rec}_{total}(\theta,\phi)=K^{1}P^{tr}_{total}(\theta,\phi)\,. \tag{13}$$

Integrating gives:

$$\frac{S}{4\pi}\int_0^{\pi}\int_0^{2\pi}A_r(\theta^1,\phi^1)Sin\theta^1 d\theta^1 d\phi^1$$

$$=\frac{K}{4\pi r^2}\int_0^{\pi}\int_0^{2\pi}P^{tr}_{total}(\theta^1,\phi^1)r^2 Sin\theta^1,\phi^1 d\theta^1 d\phi^1\,. \tag{14}$$

If the ratio of Eqs. (13) and (14) is taken, one obtains:

$$\frac{A_r(\theta,\phi)}{\overline{A}_r}=D(\theta,\phi)\,, \tag{15}$$

in which $D(\theta,\phi)$ is the directivity of antenna when it is transmitting as given by Eq. (7). Then $\overline{A}_r$ is the average receiving cross section of the antenna, defined by

$$\overline{A}_r=\frac{1}{4\pi}\int_0^{\pi}\int_0^{2\pi}A_r(\theta^1,\phi^1)Sin\theta' d\theta' d\phi'\,. \tag{16}$$

Antenna Half-power Beamwidth

The half-power beamwidth is defined as "in a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half the maximum value of the beam". Often the term beamwidth is used to describe the angle between any two points on the pattern, such as the angle between the 10dB points. However, the term beamwidth by itself is usually reversed to describe the 3-dB beamwidth.

The beamwidth of the antenna is a very important figure of merit, and it is often used to describe its tradeoff with the side lobe level, that is, as the beamwidth decreases, the side lobe increases and vice versa. In addition, the beamwidth of the antenna is also used to describe the resolution capabilities of the antenna to distinguish between two adjacent radiating sources. The most common resolution criterion states that the resolution capability of an antenna to distinguish between two sources is equal to half the first null beamwidth (FNBW/2), which is usually used to approximate the half power beamwidth (HPBW). That is, two sources separated by angular distances equal or greater than

FNBW/2 HPBW of an antenna with a uniform distribution can be resolved. If the separation is smaller, then the antenna will tend to smooth the angular separation distance.

Beam Efficiency

The beam efficiency of a receiving antenna with its major lobe directed along the *Z*-axis is defined by

$$BE = \frac{\text{Power received within cone angle}}{\text{Power received by the antena}} . \quad (17)$$

Given that θ is the half-angle of the cone within the percentage of the total power, hence,

$$BE = \frac{\int_0^{2\pi}\int_0^{\theta} U(\theta,\phi) Sin\theta d\theta d\phi}{\int_0^{2\pi}\int_0^{\pi} U(\theta,\phi) Sin\theta d\theta d\phi} , \quad (18)$$

where θ is chosen as the angle where the first null or minimum occurs. Then the beam efficiency will indicate the amount of power in the major lobe compared to the total power. A very high beam efficiency (between the nulls or minimums), usually in the high 90s, is necessary for an antenna used where received signals through the minor lobes must be minimized.

Radiation Pattern Lobes

Various parts of a radiation pattern are referred to as lobes, which may be sub-classified into major or main, minor, side and back lobes. A radiation lobe is a portion of the radiation pattern bounded by regions of relatively weak radiation intensity. Minor lobes usually represent radiation in undesired directions and they should be minimized as shown in Fig. 4.

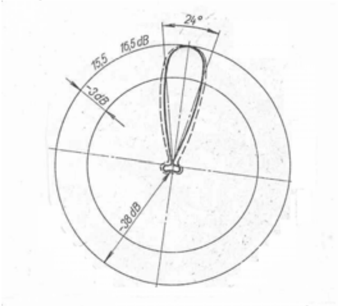

Fig. 4. The radiation pattern of the designed yagi array antenna.

Side lobes are normally expressed as a ratio of the power density in the lobe in question to that of the major lobe. This ratio is often termed the side lobe ratio or side lobe level. Side lobes levels of -20dB or smaller are usually not desirable in most applications. Attainment of a side lobe level smaller than -30 dB usually requires very careful design and construction.

Analysis of the Results

From the results obtained in Table A.1 in the Appendix and from Eqs. (3) to (5), it could be observed that the signal received is a superposition of both direct and reflected signals which resulted into multiple images due to the impact of the hills. This implies that hills on a transmission path have much effect on the reception of television signals. Variations in the contour and roughness of the terrain, including any scatters that are present, cause changes in reception as a result of specular reflection, diffuse reflection and diffraction. This also shows that television signals reach the TV receiver by a longer path after reflection on the hills. With the application of the designed antenna which is capable of rejecting the reflected signal due to its pointing optimization to receive the direct signal and discriminate against the delay signals, the problem of ghosting was minimized to the bearable level. Hence, antennas with narrow beamwidth, high directivity and high gain could become the preferred solution to the problem of ghosting in this mountainous area.

Conclusion

As a ghost image corresponds to a second version of the signal from the TV station, reflected from a large object and thus arriving via a longer path, this means that often it is also arriving form a different direction. So with a large gain and a very directional antenna it is often possible to swing the antenna around a little to the left or to the right so that it still receives the direct path signal at good strength, but picks up very little of the reflected path signal that was responsible for the ghost.

Recommendation

In really stubborn cases where a single very directional antenna cannot reject the reflected path signal enough by itself to lay the ghost, it is possible to use a second very directional antenna to receive the reflected path signal by itself, and then add this antenna's signal to that from the main antenna with the connections reversed so the reflected path is cancelled out.

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Appendix

Table A.1. Field strength signal measured at the main Town of Idanre.

S/N	Identified Towns	Line of sight distance from transmitter (km)	Field strength (dB)	Field strength (mV/m)	Path loss in dB.	Height of the location above sea level (m).	Nature of the video signal received	Nature of terrain
1	Gbekemu	16.75	32.00	0.0398	63	360	Multiple image	Rounded by hill
2	Afribank-Idanre	16.80	34.00	0.050	61	330	Multiple image	,,
3	Methodist High school. Idanre	17.00	27.00	0.0224	68	350	Multiple Image	,,
4	Ese-Gbeke Idanre	17.50	14.00	0.0050	81	332	Multiple Image	,,
5	Oke Idanre	17.85	66.00	1.995	29	364	clear	Clear line of sight
6	Depo St Idanre	18.00	36.00	0.063	59	330	Multiple Image	Rounded by hill.
7	Oja-Ale Idanre	18.25	40.00	0.100	55	349	Multiple Image	,,
8	Isalu Idanre	18.95	32.00	0.040	63	330	Multiple Image	,,
9	Opa	17.00	29.00	0.028	66	288	Multiple Image	,,
10	Odole	17.90	34.00	0.050	61	303	Multiple Image	,,

Appendix IV: Contour Map of Akure south west showing the main town of Idanre.

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Fig. A.1. The contour map of main bowl of Odode Idanre (Scale: 1:50,000).