JAM: Jurnal Arkeologi Malaysia
38(2) (2025): 45-61

# RESEARCH ON BOWL-TYPE PORCELAIN FROM THE "WANLI" SHIPWRECK BASED ON THE FRACTAL MAPPING QUANTIFICATION METHOD

# PENYELIDIKAN PORSELAIN JENIS MANGKUK DARIPADA KAPAL KARAM "WANLI" BERDASARKAN KAEDAH KUANTIFIKASI PEMETAAN FRAKTAL

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Received: 11th August 2025 Accepted: 16th September 2025

**Abstract**

The Wanli shipwreck, as a representative Late Ming Dynasty shipwreck discovered in Malaysia, yielded tens of thousands of blue and white porcelain artifacts from the Late Ming period. Among these, bowls constitute the majority and can be categorized into large, medium, and small bowls based on their shapes. This study aims to apply the fractal mapping quantification method to filter and extract the sample contours of the bowls recovered from the Wanli shipwreck. It will encode and quantitatively analyze the morphological characteristics of different bowl types, exploring the relationship between local morphological evolution and functionality, as well as the proportional scale relationships between local and overall form. The goal is to determine the range of shape variations and key characteristics of these bowl types. Since the form and function of vessel shapes are closely linked, this study integrates data analysis with historical records and academic research to systematically classify the bowl types found in the shipwreck. It seeks to identify the characteristics of export-oriented blue and white porcelain bowls from the Late Ming Dynasty and examine how their forms were influenced by ceramic-making techniques, aesthetic trends, and daily habits. Additionally, the establishment of a typological mapping database for Ming Dynasty blue and white porcelain can serve as a valuable reference for future digital preservation and redesign efforts.

**Keywords:** Wanli shipwreck, bowl, fractal mapping, quantitative analysis

***Abstrak***

*Kapal karam Wanli merupakan salah sebuah kapal karam daripada Dinasti Ming Akhir yang ditemui di Malaysia dengan muatan puluhan ribu artifak porselin biru dan putih dari zaman Ming Akhir. Majoriti artifak yang ditemui adalah jenis mangkuk dan boleh dikategorikan kepada mangkuk besar, sederhana dan kecil berdasarkan bentuknya. Kajian ini menggunakan kaedah kuantifikasi pemetaan fraktal bagi mengelaskan dan mengidentifikasi kontur sampel mangkuk yang ditemui dari kapal karam Wanli. Ia akan mengekod dan menganalisis secara kuantitatif ciri-ciri morfologi pelbagai jenis mangkuk dan melihat perkaitan antara evolusi morfologi setempat dengan fungsi dan skala hubungan antara bentuk setempat secara secara keseluruhannya. Objektifnya adalah untuk menentukan julat variasi bentuk dan ciri-ciri utama jenis mangkuk ini. Memandangkan bentuk dan fungsi bekas mangkuk adalah saling berkaitan, kajian ini menggabungkan analisis data dengan rekod sejarah dan penyelidikan akademik untuk* *mengklasifikasikan jenis mangkuk daripada kapal karam tersebut secara sistematik. Ia bertujuan mengenal pasti ciri-ciri mangkuk porselin biru dan putih yang berorientasikan eksport dari Dinasti Ming Akhir serta mengkaji bagaimana bentuknya dipengaruhi oleh teknik pembuatan seramik, aliran estetik dan amalan harian. Selain itu, pembinaan pangkalan data pemetaan tipologi bagi porselin biru dan putih Dinasti Ming boleh menjadi rujukan yang berharga untuk usaha pemeliharaan digital dan reka bentuk semula pada masa hadapan.*

***Kata Kunci**: Kapal karam Wanli, mangkuk, pemetaan fraktal, analisis kuantitatif*

## INTRODUCTION

From the 15th to the 17th century, Southeast Asia exhibited a certain continuity in religious reform, urban expansion, state formation and alliances, as well as participation in commerce (Koh & Bonate 2017). Southeast Asian historian Anthony Reid even termed this period the "Age of Commerce"(Reid 2004), arguing that beyond spices, goods such as silver, textiles, glass, metalware, and ceramics also played a crucial role in the early globalization process (Reid 1990; Liu 2016). The study of "export ceramics" or "maritime ceramics" has become a significant focus in Southeast Asian maritime archaeology (Fahy 2015; Brown 2004a), contributing to the understanding of global social life. Due to the central role of ceramics in ship cargo, maritime trade during the Age of Exploration has been referred to as the "Ceramic Route" (Wu 2016). Located at the heart of the "Ceramic Route", Malaysia served as a key hub (Chen et al. 2024). In addition to the discovery of ceramics in burials and residential caves (Harrisson 1975; Chin 1988), a significant number of ancient ceramics have also been found in shipwrecks (Yatim 1978; Saiffuddin et al. 2025; Baco & Chia 2020; Masbaka 2023; Basrah & Bala 2009).

According to the official statistical records of Malaysia National Heritage (Jabatan Warisan Malaysia - JWN) as of May 13, 2015, a total of 102 shipwreck sites have been identified in the waters of Peninsular Malaysia (Ahmad Asyriq 2015; Amirah & Muhamad 2023; Jusoh et al. 2022). Among them, eight shipwrecks from the Ming Dynasty have been discovered (Baco et al. 2022; Orillaneda 2012): Turiang (1370), Nanyang (1380), Longquan (1380), Royal Nanhai (1460), Xuande (1540), Singtai (1550), Nassau (1606), and Wanli (1625) (Figure 1). Among these shipwrecks, those with a significant proportion of ceramic finds include Turiang, Longquan, and Wanli (Masbaka et al. 2025; Flecker 2012).

Notably, the Wanli shipwreck contains the largest number of recovered blue and white porcelain pieces, featuring the most diverse decorative styles (Yang 2021; Zhu et al. 2016). Since this study employs the fractal mapping method, it requires quantifiable ceramic samples, with a particular focus on both the quantity and quality of bowl samples. Given that blue and white porcelain was a major category of Ming and Qing Dynasty export ceramics, its significance in maritime trade research is undeniable. Based on these research criteria and objectives, this study selects blue and white porcelain bowls from the Wanli shipwreck as the primary research subject among the eight discovered Ming Dynasty shipwrecks (Brown 2004b).


Figure 1. Major Shipwrecks discovered in Malaysia.
(Source: Modified from https://www.maritimeasia.ws/)

The remains of the Wanli shipwreck in Malaysia were discovered approximately 60 nautical miles offshore from Tanjong Jara on the east coast of Malaysia, at a depth of about 40 meters (Figure 2). The shipwreck was excavated by Sten Sjostrand. It was named after the Wanli period due to the large quantity of Wanli-style porcelain found in the wreck (Liu 2015). A total of approximately 37,300 ceramic pieces were salvaged from the wreck, with Ming blue and white porcelain being the most abundant (Sjostrand & Syed Idrus 2007). The recovered vessel types include bowls, plates, covered boxes, and kendi (spouted pouring vessels).

The decorative motifs found on these pieces include Babao (Eight Treasures), landscape rock patterns, and dragon-phoenix designs, with a significant number of Kraak porcelain featuring cartouche decorations. These shipwreck artifacts play a crucial role in explaining the distribution of ancient ceramic trade, ceramic production, and the geopolitical significance of Peninsular Malaysia and Southeast Asia within the trade network connecting India and China (Yatim & Rashid 2013; Zhang et al. 2020; Mustapa et al. 2023).

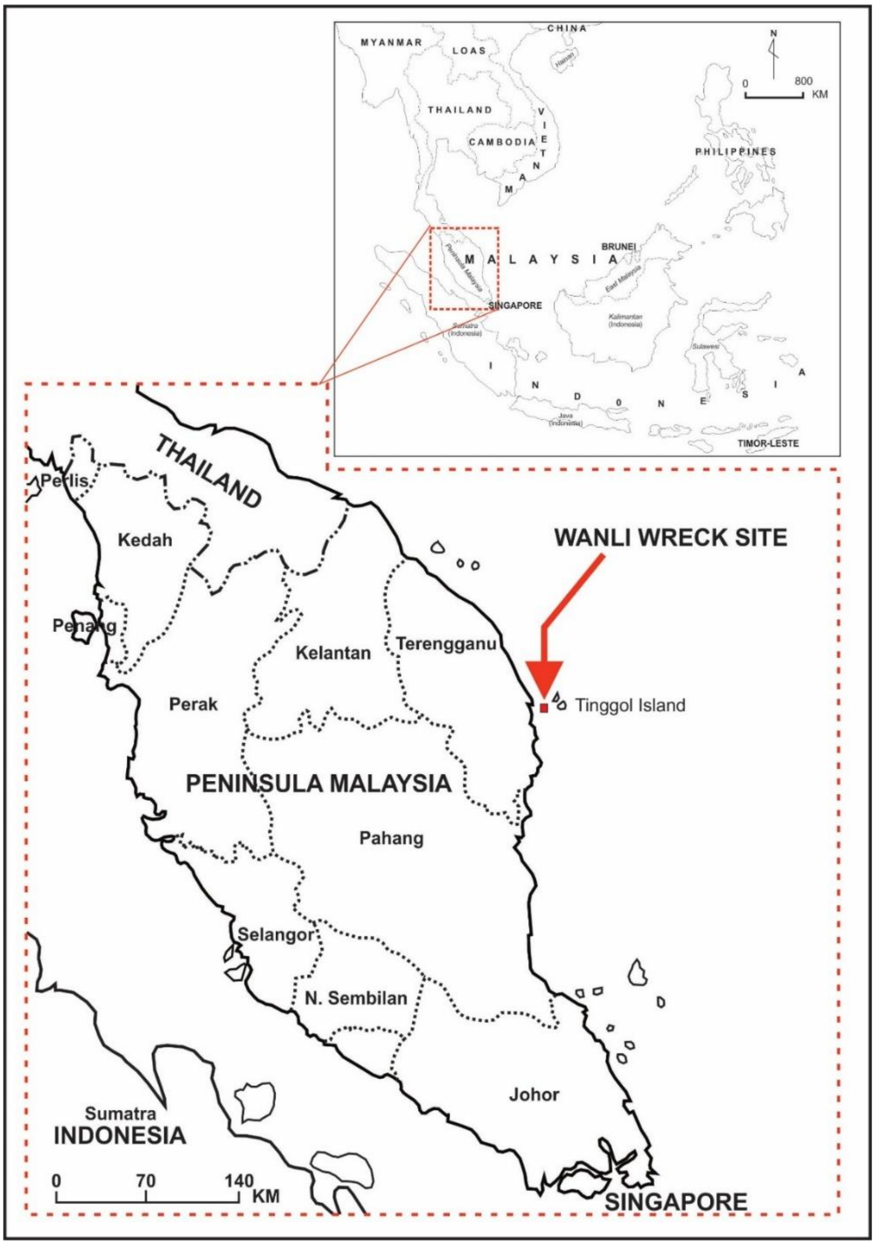


Figure 2. The location of Wanli Wreck Site.
(Source: Modified from Sjostrand & Syed Idrus 2007)

## THE CERAMIC SAMPLES

Although a total of 37,300 ceramic artifacts were recovered from the Wanli Shipwreck, the majority were severely damaged, with only 7,543 specimens (less than 50% fragmented). Among these, intact and partially preserved bowls constituted the largest proportion of the recovered blue-and-white porcelain (Liu 2015). This study selects 27 bowl samples that effectively represent the bowl contours. These include 9 typical examples each of large (Figure 3), medium (Figure 4), and small-sized bowls (Figure 5). The majority of the samples were provided by Mr. Ben Rongen, who participated in the salvage operation. Only one bowl sample (WLH-99) comes from the Lembah Bujang Archaeological Museum, which holds the sole Wanli shipwreck bowl in its collection.


Figure 3. Large porcelain bowls classified as Type A.


Figure 4. A medium-sized porcelain bowls classified as Type B.


Figure 5. A small-sized porcelain bowls classified as Type C.

The selection of 27 bowl samples in this study was based on several considerations. First, apart from bowls and dishes, the number of other vessel types is too limited to form a comparable dataset. Second, although more than 30,000 artifacts were recovered from the shipwreck, most are severely damaged. Because the rims of the vessels are generally thin, the majority are broken and therefore unsuitable for sampling. Among the more than 7,000 artifacts with less than 50% damage, bowls account for 39.3%, or approximately 290 pieces. However, most of these fragments lack complete rims, bases, or sufficient diagnostic features, and many are highly repetitive. Therefore, taking into account the typological representativeness and the availability of clear rim, base, and height information, 27 samples were selected, covering large, medium, and small types. Importantly, the fractal mapping quantification method does not depend on large-scale statistical sampling but rather emphasizes the extraction of typical curves and morphological features. These samples encompass the principal morphological types of bowls recovered from the shipwreck and can, to a considerable extent, reflect the proportional and functional characteristics of late Ming daily-use ceramics. Although the number of samples is limited, given the methodological requirements, recovery conditions, and sampling constraints, this selection is reasonable and sufficient to support the analyses and conclusions presented in this study.

## RESEARCH METHODOLOGY

The fractal mapping quantification method is an approach used in archaeology and cultural heritage research. It aims to quantitatively analyze the morphological characteristics of artifacts to reveal differences and connections between different cultural layers or historical periods (Lucena et al. 2014). Sometimes referred to as the fractal mapping method, it is a graphical analysis technique that combines statistical data to scientifically examine the underlying causes of morphological variations (Han & Li 2014).

This study will first employ archaeological typology methods to classify the bowls based on differences in their morphological characteristics. It will then visually present the connections and distinctions between the artifacts. By applying the fractal mapping quantification method, a quantitative analysis of 27 Wanli shipwreck blue and white porcelain bowl samples will be conducted. The bowl shapes will be encoded and categorized based on their morphological features. Each type will be placed within a matrix grid for comparison, identifying similarities and differences. This approach aims to uncover patterns of morphological evolution and trace the underlying reasons for their development.

## QUANTITATIF ANALYSIS

The fractal mapping quantification method applied to the blue-and-white porcelain bowls recovered from the Wanli Shipwreck was based on archaeological typology for classifying specimens into types and variants. This involved extracting the outer contour line images of the samples and converting them into standardized typological diagrams. Through computational analysis, key morphological parameters were derived, including the curvature values of the bowl's belly, height-to-diameter ratios, and mouth-to-foot ratios. Comparative analysis of these sample data enabled the establishment of a specialized typological classification system for bowls from late Ming Dynasty shipwrecks.

### Typological Classification

Typological classification of samples is a fundamental research method in archaeological typology, as each category of artifact typically exhibits distinct functional purposes and formal characteristics. The process of typological classification and sub-division forms the essential basis for subsequent contour extraction and quantitative analysis (Karasik & Smilansky 2011). During the classification process, types must be treated separately in accordance with the principle of mutual exclusivity (Adams 2012; Kafetzaki et al. 2023). Based on sample information (Tables 1-3; Figure 3-4), the blue and white porcelain bowls recovered from the shipwreck are primarily divided into three formal types - Type A, B, and C, corresponding respectively to large bowls (height ≥ 80 mm), medium bowls (height between 60 mm to 80 mm), and small bowls (height < 60 mm).

Table 1. Typological data of type A samples.

| Sample Name | Height (mm) | Diameter (mm) | Color | | | |
|---|---|---|---|---|---|---|
| | | | Dark pigment | Light pigment | Glaze | Body |
| WLH-27 | 94 | 216 (rim); 91 (foot) | greenish black (10BG 2.5/1) | light bluish gray (5PB 7/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-65 | 92 | 220 (rim); 87 (foot) | very dark bluish gray (10B 3/1) | bluish gray (10B 5/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-68 | 94.5 | 220 (rim); 86 (foot) | very dark bluish gray (5PB 3/1) | bluish gray (5PB 5/1) | light greenish gray (5GY 8/1) | white (N 8.5/) |
| WLH-76 | 103.7 | 220-222 (rim); 90 (foot) | very dark bluish gray (10B 3/1) | bluish gray (5PB 5/1) | light greenish gray (5BG 8/1) | white (N 8.5/) |
| WLH-78 | 98.5 | 212-219 (rim); 88 (foot) | bluish black (5PB 2.5/1) | bluish gray (5B 5/1) | light bluish gray (5B 8/1) | White (N 8.5/) |
| WLH-80 | 96.4 | 218 (rim); 80 (foot) | very dark bluish gray (10B 3/1) | bluish gray (5PB 5/1) | light bluish gray (10B 8/1) | white (N 8.5/) |
| WLH-135 | 95 | 220 (rim); 87 (foot) | greenish black (5BG 2.5/1) | bluish gray (5B 5/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-136 | 98 | 228 (rim); 88 (foot) | very dark bluish gray (5B 3/1) | bluish gray (5PB 6/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-172 | 89 | 144 (rim); 80 (foot) | bluish black (5B 2.5/1) | bluish gray (10B 5/1) | light greenish gray (5GY 8/1) | white (N 8.5/) |

Table 2. Typological data of type B samples.

| **Sample Name** | **Height (mm)** | **Diameter (cm)** | **Color** | | | |
|---|---|---|---|---|---|---|
| | | | **Dark pigment** | **Light pigment** | **Glaze** | **Body** |
| WLH-09 | 63.7 | 141 (rim); 56 (foot) | very dark bluish gray (5PB 3/1) | bluish gray (5PB 6/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-12 | 66.5 | 144 (rim); 49 (foot) | very dark gray (5PB 3/1) | bluish gray (5PB 5/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-17 | 66 | 140 (rim); 51 (foot) | very dark bluish gray (5PB 3/1) | bluish gray (10B 5/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-19 | 69 | 140 (rim); 56 (foot) | very dark gray (5PB 3/1) | bluish gray (10BG 5/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-23 | 76 | 140 (rim); 48 (foot) | bluish black (5B 2.5/1) | bluish gray (10B 5/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-28 | 63.3 | 160 (rim); 66 (foot) | dark bluish gray (5PB 4/1) | bluish gray (5PB 6/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-31 | 76.4 | 146 (rim); 50 (foot) | dark bluish gray (5PB 4/1) | bluish gray (5B 6/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-99 | 73.6 | 160-167 (rim); 71 (foot) | bluish black (5PB 2.5/1) | greenish gray (10BG 6/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-171 | 73 | 144 (rim); 49 (foot) | bluish black (5PB 2.5/1) | bluish gray (5PB 6/1) | light bluish gray (5B 8/1) | white (N 8.5/) |

Table 3. Typological data of type B samples.

| Sample Name | Height (mm) | Diameter (cm) | Color | | | |
|---|---|---|---|---|---|---|
| | | | Dark pigment | Light pigment | Glaze | Body |
| WLH-03 | 44.7 | 90 (rim); 36 (foot) | very dark bluish gray (10B 3/1) | bluish gray (5PB 5/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-06 | 57 | 126-132 (rim); 51 (foot) | very dark gray (5PB 3/1) | bluish gray (5PB 5/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-22 | 56.8 | 120 (rim); 40 (foot) | very dark bluish gray (5PB 3/1) | bluish gray (10B 5/1) | light bluish gray (5B 8/1) | White (N 8.5/) |
| WLH-169 | 51 | 88 (rim); 34 (foot) | very dark gray (5PB 3/1) | bluish gray (10BG 5/1) | light bluish gray (5B 8/1) | White (N 8/) |
| WLH-170 | 48 | 92 (rim); 35 (foot) | very dark bluish gray (10B 3/1) | bluish gray (5B 6/1) | light bluish gray (5B 8/1) | white (N 8/) |
| WLH-210 | 59 | 120 (rim); 44 (foot) | very dark bluish gray (5PB 3/1) | bluish gray (5PB 6/1) | light bluish gray (5GY 8/1) | White (N 9/) |
| WLH-223 | 48 | 80 (rim); 36 (foot) | dark bluish gray (5PB 4/1) | light bluish gray (5B 6/1) | light bluish gray (5B 8/1) | white (N 8.5/) |
| WLH-225 | 47 | 90 (rim); 36 (foot) | bluish gray (5PB 5/1) | bluish gray (10BG 6/1) | light greenish gray (5B 8/1) | white (N 8.5/) |
| WLH-226 | 46 | 96 (rim); 47 (foot) | very bluish black (5PB 3/1) | bluish gray (5PB 5/1) | light bluish gray (5B 8/1) | white (N 8.5/) |

**Countour Extraction**

Based on rim characteristics (Figure 6), large bowls can be classified into three primary rim types: open-rims (WLH-27, WLH-65, WLH-78, WLH-80), flaring-rims (WLH-68, WLH-76, WLH-135, WLH-136), and converging-rims (WLH-172). While rim diameters generally remain consistent at approximately 22 cm, some exceptions exist. For instance, sample WLH-172, which exhibits a basin-shaped form, has a notably smaller rim diameter of 14.4 cm. All large bowls display curvilinear bodies, though the degree of curvature varies significantly. Compared to medium and small bowls, large bowls demonstrate greater variation in body curvature. The typical height of large bowls is around 95 mm, though a few oversized examples exist, such as WLH-76, which reaches a height of 103.8 mm.

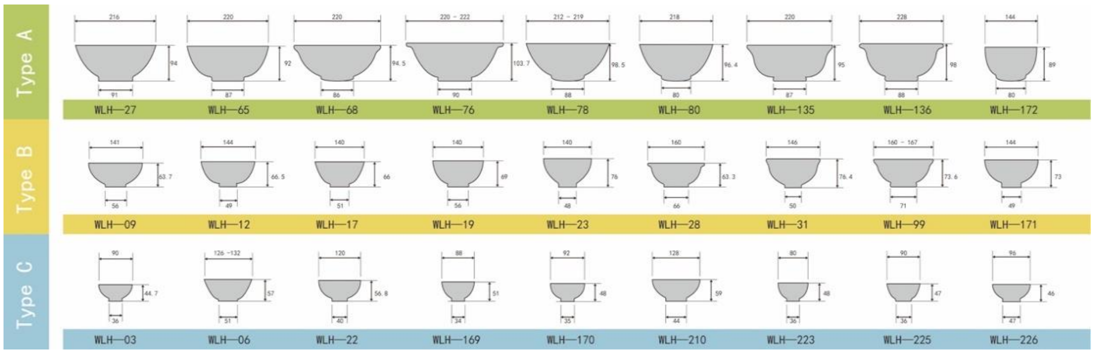


Figure 6. Contour extraction diagram of type bowls.

Medium-sized bowls can be categorized into three main rim types based on their morphological features (Figure 6): converging-rims (WLH-09, WLH-19, WLH-23, WLH-171), flaring-rims (WLH-28, WLH-31, WLH-99), and open-rims (WLH-12, WLH-17). All examples exhibit curved bodies (carinated profiles), with relatively consistent degrees of curvature - unlike large bowls, which display greater variation in their belly profiles. The rim diameters of medium bowls generally range between 14 to 15 cm, and their heights average around 65 mm. Both measurements exhibit a narrow range of variation, suggesting a relatively standardized size and form within this category.

Small bowls can be broadly divided into two rim types (Figure 6): converging-rims (WLH-03, WLH-22 WLH-169, WLH-170, WLH-210; WLH-223; WLH-226) and open-rims (WLH-06, WLH-225). Compared to large and medium-sized bowls, small bowls are generally smaller and thinner, with the thinnest rim measuring only 0.2 cm in thickness. The overall height of small bowls varies more significantly than that of medium bowls, ranging from 44 mm to 59 mm. Morphological changes in both rim and body are relatively minimal; most bowls feature constricted rims and inward-curving bodies with consistent curvature, similar to medium bowls. This morphological stability may be related to functional constraints.

**Contour-Based Typological Comparison**

Based on the previous typological definitions and contour extraction, the rim curvature of each bowl type - converging-rim, flaring-rim, and open-rim is coded according to the angle and direction of inclination. These are presented in the integrated diagrams (Figure 7–9), where each type is placed in a matrix grid: the x-axis indicates rim diameter (mm), and the y-axis denotes bowl height (mm). On the right side of each matrix is a comparative integration of contour changes among bowls of the same rim type but different sizes, while the left side shows a localized analysis of the rounded belly area. Red dots indicate measured maximum belly widths along the contour line. The analysis shows that, aside from a few outliers, the overall contour similarity among bowl types is high, with major differences concentrated at the rim and base.

The converging-rim bowl (Figure 7), also known as a constricted-rim bowl, features inward-curving rims. These can be subdivided into two types: (1) rims that curve inward directly, forming a bud-like shape, and (2) rims that flare outward slightly before converging near the lip (Liu & Wu, 2024). The specimens analyzed here fall into the second category, with subtle inward curvature near the rim. Although similar in appearance to alms bowls, converging-rim bowls differ in that the latter generally have more cylindrical bellies and greater capacity. According to the right-side matrix, this type is largely confined to small and medium sizes. The scarcity of large-sized examples may be related to functional requirements: the inward-curving rim facilitates scooping while preventing contents from spilling due to wall expansion.

Belly region analysis shows high overlap among medium and small converging-rim bowls, with bellies typically located at the midpoint of the vessel's height. No significant upward or downward shift in belly position is observed with increased size. Medium-sized specimens have belly widths ranging from 41–60 mm, while small ones range from 37–59 mm. The medium type is deeper and more upright, offering better heat retention and capacity. In contrast, small converging-rim bowls are shallower and more open, suitable for small portions of solid food, and ideal for transport or child use due to their lightweight nature.

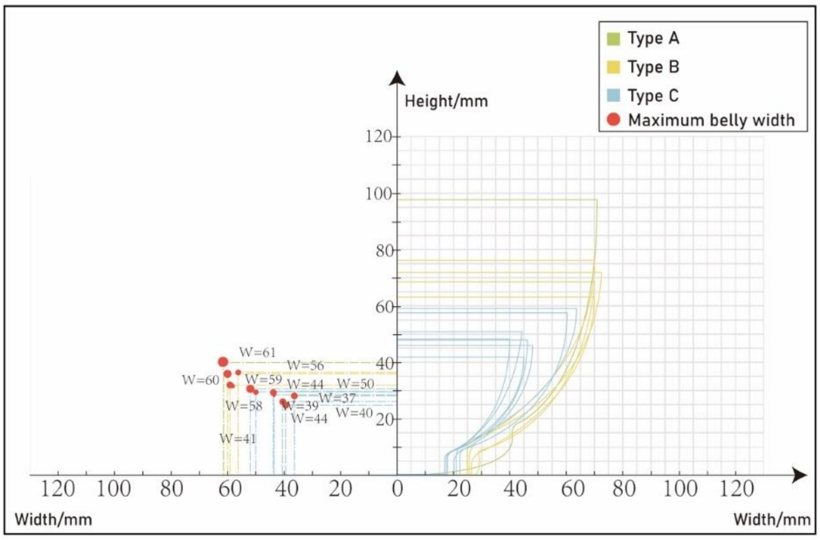


Figure 7. Localized analysis of converging-rim bowl.

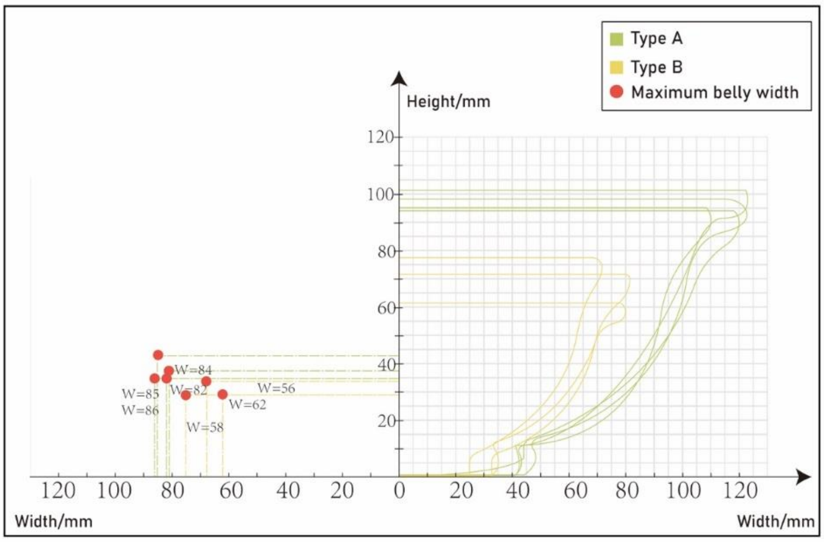


Figure 8. Localized analysis of flaring-rim bowl.

The flaring-rim bowl (Figure 8) features rims that extend outward and sometimes fold slightly downward, creating an inverse curve against the body. This trumpet-like profile enhances openness and improves usability by making it easier to grip without burning the hand when filled with hot food (Liu & Wu 2024). Large flaring-rim bowls range from 94.5–103.7 mm in height, with rim diameters of 220–228 mm and belly widths of 82–86 mm. These represent classic wide-rim, semi-deep forms suitable for shared meals or fast-cooling liquids, emphasizing openness and low-centre stability.

In contrast, medium-sized flaring-rim bowls (63.3–76.4 mm in height, 146–160.7 mm in rim diameter, and 56–62 mm in belly width) show more pronounced curvature contraction between rim and belly. The belly is more protruded, enhancing heat retention and making them more suitable for individual servings. Notably, in terms of vertical belly placement, large examples tend to have bellies that shift downward with increasing height, while medium types maintain a more central belly, creating a more balanced form.

The open-rim bowl (Figure 9) has rims and upper walls that extend outward, though without the dramatic flare of the flaring-rim type. The outer contour appears nearly linear near the rim, distinguishing it from the trumpet-shaped mouth of the flaring type. This design facilitates demolding in mold-based production and aligns with the natural curvature formed in wheel-throwing processes, making it highly practical. Both flaring and open-rim forms improve pouring efficiency and ease of cleaning, preventing residue buildup. Their presence across all size categories attests to their practical popularity.

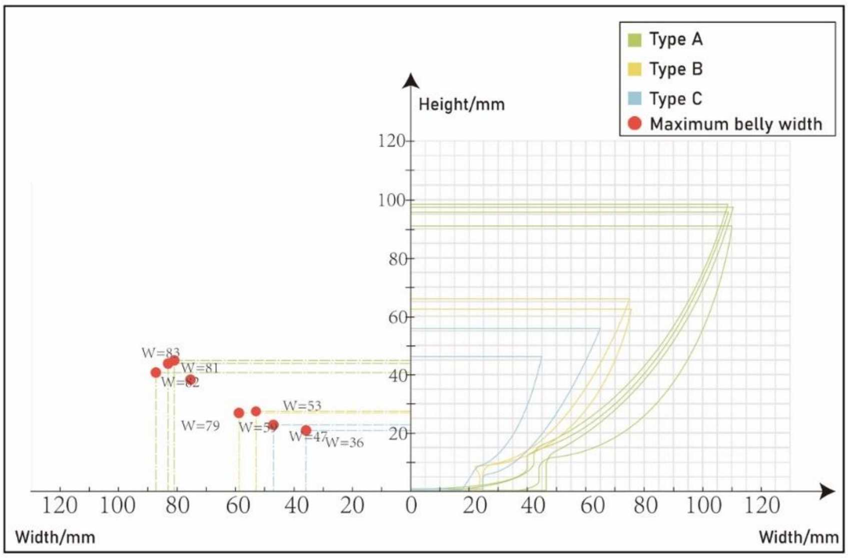


Figure 9. Localized analysis of open-rim bowl.

Large open-rim bowls (92–98.5 mm high; 212–220 mm rim diameter; 79–83 mm belly width) exhibit shallow profiles. Medium bowls (66–66.5 mm high; 140–144 mm rim diameter; 53–59 mm belly width) appear more compact in proportion, with minimal variation across specimens—suggesting familiarity and precision in production by contemporary artisans. Small open-rim bowls (47–57 mm high; 90–132 mm rim diameter; 36–47 mm belly width) are lightweight and verge toward dish-like forms. These may have been used for small portions of solid food, sauces, or by children. Their limited capacity and low belly-to-height ratios suggest ease of cleaning, storage, and transport, making them ideal for individual use and meal division.

**Quantitative Diagrammatic Data Analysis**

As visualized in Figure 10, the coordinate values of rim diameter and height for each sample are plotted, with the horizontal axis representing rim diameter and the vertical axis representing height. The overall distribution reveals a clear trend: sample heights range from a minimum of 44.7 mm (WLH-03) to a maximum of 103.7 mm (WLH-76), with an average of approximately 72.1 mm; rim diameters range from 80 mm (WLH-223) to 228 mm (WLH-136), averaging about 153.1 mm. A positive correlation is observed between rim diameter and height, indicating that changes in one variable tend to correspond with changes in the other. In general, samples with larger rim diameters also exhibit greater heights—for example, WLH-27 demonstrates both a wide rim and a tall profile.

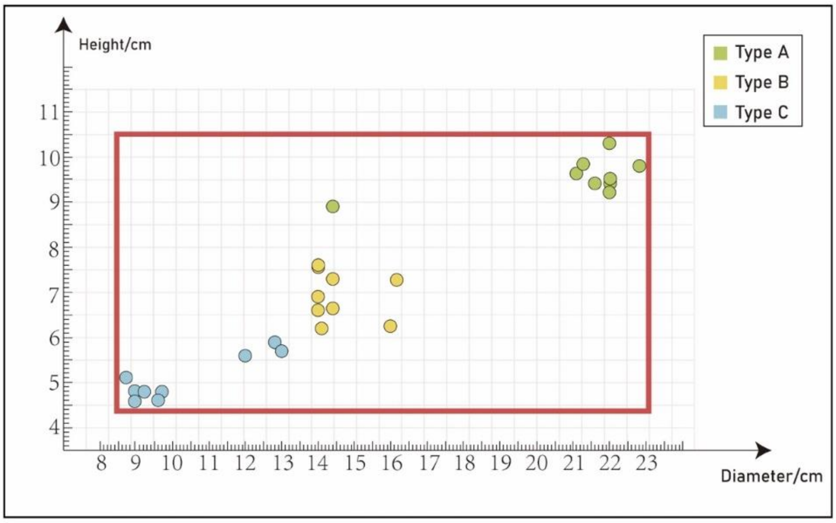


Figure 10. Visualization of rim diameter and height coordinates for bowl-type porcelain samples.

By applying the formulas Height (mm) / Rim Diameter (mm) and Rim Diameter (mm) / Foot Diameter (mm), the height-to-diameter ratio (H/D) and rim-to-foot ratio (R/F) of 27 samples listed in Table 4 were analyzed, revealing their quantitative relationships.

Table 4. Summary of sample height, rim and foot diameters, and proportional rations.

| Sample Name | Height (mm) | Mouth Rim Diameter (mm) | Foot Ring Diameter (mm) | Height-to-Diameter Ratio | Rim-to-Foot Ratio |
|---|---|---|---|---|---|
| WLH-03 | 44.7 | 90 | 36 | 0.5 | 2.5 |
| WLH-06 | 57 | 126-132 | 51 | 0.4 | 2.5 |
| WLH-09 | 63.7 | 141 | 56 | 0.5 | 2.5 |
| WLH-12 | 66.5 | 144 | 49 | 0.5 | 2.9 |
| WLH-17 | 66 | 140 | 51 | 0.5 | 2.8 |
| WLH-19 | 69 | 140 | 56 | 0.5 | 2.5 |
| WLH-22 | 56.8 | 120 | 40 | 0.5 | 3.0 |
| WLH-23 | 76 | 140 | 48 | 0.5 | 2.9 |
| WLH-27 | 94 | 216 | 91 | 0.4 | 2.4 |
| WLH-28 | 63.3 | 160 | 66 | 0.4 | 2.4 |
| WLH-31 | 76.4 | 146 | 50 | 0.5 | 2.9 |
| WLH-65 | 92 | 220 | 87 | 0.4 | 2.5 |
| WLH-68 | 94.5 | 220 | 86 | 0.4 | 2.5 |
| WLH-76 | 103.7 | 220-222 | 90 | 0.5 | 2.5 |
| WLH-78 | 98.5 | 212-219 | 88 | 0.5 | 2.5 |

| | | | | | |
|---|---|---|---|---|---|
| WLH-80 | 96.4 | 218 | 80 | 0.4 | 2.7 |
| WLH-99 | 73.6 | 160-167 | 71 | 0.5 | 2.3 |
| WLH-135 | 95 | 220 | 87 | 0.4 | 2.53 |
| WLH-136 | 98 | 228 | 88 | 0.4 | 2.6 |
| WLH-169 | 51 | 88 | 34 | 0.6 | 2.6 |
| WLH-170 | 48 | 92 | 35 | 0.5 | 2.6 |
| WLH-171 | 73 | 144 | 49 | 0.5 | 3.0 |
| WLH-172 | 89 | 144 | 80 | 0.6 | 1.8 |
| WLH-210 | 59 | 128 | 44 | 0.5 | 2.9 |
| WLH-223 | 48 | 80 | 36 | 0.6 | 2.2 |
| WLH-225 | 47 | 90 | 36 | 0.5 | 2.5 |
| WLH-226 | 46 | 96 | 47 | 0.5 | 2.0 |

The H/D ratio ranges from 0.4 to 0.6, with an average of approximately 0.5. Most samples exhibit a relatively stable H/D ratio, concentrated between 0.4 and 0.5, indicating that the height is typically 40% to 50% of the rim diameter. For example, samples with a lower H/D ratio (such as WLH-27, ratio = 0.4) tend to have a large rim diameter and comparatively smaller height, resulting in a visibly squat and broad appearance. In contrast, samples with a higher H/D ratio (such as WLH-169, ratio = 0.6) tend to have a smaller rim diameter relative to their height, giving them a visually taller and slimmer profile. Functionally, bowls with an H/D ratio between 0.4 and 0.5 typically have a shallower body, making them more suitable for containing solid foods and facilitating quicker heat dissipation. Bowls with a ratio between 0.5 and 0.6 have a deeper body, which can help prevent spillage and are more appropriate for holding semi-liquid foods.

The R/F ratio among the samples shows a wider range, spanning from 1.8 to 3.0, with an average of approximately 2.6. Most samples fall between 2.3 and 2.9, suggesting that the rim diameter is generally 2.3 to 2.9 times larger than the foot diameter. A lower R/F ratio (e.g., WLH-172, ratio = 1.8) indicates less differentiation between the rim and foot diameters, resulting in a vessel with a broader base and a more robust appearance. Conversely, a higher R/F ratio (e.g., WLH-22, ratio = 3.0) reflects a significantly larger rim diameter relative to the foot, suggesting a narrower base. It is worth noting that WLH-172, with a notably low R/F ratio of 1.8, deviates from the general trend and may represent a different form type, possibly a deep bowl or alms bowl, indicating a potentially different function from the others.

The data visualizations further indicate a positive correlation between the H/D and R/F ratios, with both ratios showing relatively stable values across most samples. This suggests adherence to a consistent proportional design. A smaller R/F ratio (i.e., a wider foot) typically implies a larger supporting area and greater stability. The selection of appropriate ratios likely reflects functional considerations such as interior volume, ease of handling, material efficiency, and aesthetic harmony. Therefore, maintaining the R/F ratio within a suitable range ensures the vessel's usability, energy efficiency, and visual balance (Banducci 2014).

## SUMMARY AND CONCLUSION

The vessel form constitutes a fundamental element in the typological identification of ancient Chinese ceramics. This study focuses on porcelain bowls recovered from the Wanli shipwreck as the primary object of analysis. Drawing upon photographs of extant artifacts and referencing historical textual sources, the research examines the classification of bowl forms, identifies patterns in localized morphological features, and explores the overall formal characteristics of the vessel types discovered on the wreck.

By integrating mathematical and quantitative methodologies into ceramic studies, this paper applies standardized morphometric analysis to investigate the relationship between formal variation and functional utility in late Ming dynasty bowls. Particular attention is given to the rim, a key structural component that facilitates both food containment and lip contact. The rim is also the most visually distinctive feature of the bowl and can serve as a basis for typological naming. As a common domestic utensil, the bowl's primary functions include containing and delivering food. Its circular form-free of sharp angles-offers ergonomic comfort during use and, due to the efficiency of curved profiles, often provides greater internal capacity than square or rectilinear alternatives, making it a highly practical vessel shape.

George Nelson once pointed out that "culture is often permanently preserved in specific times and spaces through material objects" (Li 2015). The large-scale exportation of Chinese ceramics was not only an economic phenomenon but also a cultural one. According to historical records, between 1605 and 1661, the Dutch East India Company transported approximately five million pieces of Chinese ceramics to regions such as Annam and Siam (Peng 2017), and in the single year of 1636 alone, more than 370,000 pieces were shipped to Malaysia and Indonesia (Wan 2009). During the late Ming period, China exported a considerable quantity of ceramics abroad, which enriched the lifestyles of overseas populations and, in some regions, even directly transformed local customs. For instance, prior to the introduction of Chinese ceramics, some Southeast Asian societies commonly relied on natural materials such as leaves and nutshells as food containers (Zhang 1981; Cao 2008; Fang 2013; Li 2022). Following the arrival of Chinese ceramics, they became indispensable in daily life, altering dietary habits, enhancing culinary culture, and ultimately reshaping social practices. During this dissemination, Chinese ceramics integrated with local cultural traditions, social customs, and religious practices, thereby promoting the economic and cultural development of the recipient countries and regions, and enriching the connotations of Sino-foreign exchanges during this period (Gan 2008).

The fractal mapping quantification method enhances both the accuracy and reliability of classification, revealing developmental trends and morphological evolution in late Ming blue-and-white porcelain bowls. Furthermore, standardized digital descriptions facilitate data integration and management, laying the foundation for a robust digital database system that supports the long-term preservation, comparative study, and management of blue-and-white porcelain artifacts.

## ACKNOWLEDGEMENTS

This study is made possible with the support of several people and organisations. First, we would like to thank the Director of the Lembah Bujang Archaeological Museum, Mr. Azhar Bin Mohamed Noor and his staff for their kind assistance. We are also very grateful to the Nanhai Marine Archaeology Sdn. Bhd, Mr. Ben Rongen and wife for their help and the samples provided during the research. We owe special thanks to Mr. Sairul Ramle and Mr. Fadly Jusoh of Earth Material Characterisation Laboratory, Global Archaeological Research Centre, Universitiy Sains Malaysia, for the support of this research.

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