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Ocena wpływu wybranych atrybutów fizycznych, lokalizacyjnych i środowiskowych na ceny nieruchomości lokalowych

Praca wykonana pod kierunkiem

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1. Wykaz prac naukowych wchodzących w skład zbioru

Badania doktorskie kandydata zostały przedstawione w następujących opublikowanych pracach naukowych:

1. **Chwiałkowski, C.**; Zydroń, A. Socio-Economic and Spatial Characteristics of Wielkopolski National Park: Application of the Hedonic Pricing Method. Sustainability 2021, 13, 5001. https://doi.org/10.3390/su13095001

   100 pkt[1].; IF[2] = 3.889

2. **Chwiałkowski, C.**; Zydroń, A. The Influence of Aircraft Noise on the Prices of Residential Properties on the Example of Poznań. Rocznik Ochrona Środowiska 2021, 23, 263-278. https://doi.org/10.54740/ros.2021.017

   40 pkt[1].; IF[2] = 0.618

3. **Chwiałkowski, C.**; Zydroń, A. The Impact of Urban Public Transport on Residential Transaction Prices: A Case Study of Poznań, Poland. ISPRS Int. J. Geo-Inf. 2022, 11, 74. https://doi.org/10.3390/ijgi11020074

   70 pkt[1].; IF[2] = 3.099

4. **Chwiałkowski, C.**; Zydroń, A. Influence of Railroad Infrastructure on Residential Property Prices on the Example of Kórnik Municipality. Rocznik Ochrona Środowiska 2022, 24, 54-73. https://doi.org/10.54740/ros.2022.005

   40 pkt[1].; IF[2] = 0.618

5. **Chwiałkowski, C.**; Zydroń, A.; Kayzer, D. Assessing the Impact of Selected Attributes on Dwelling Prices Using Ordinary Least Squares Regression and Geographically Weighted Regression: A Case Study in Poznań, Poland. Land 2023, 12, 125. https://doi.org/10.3390/land12010125

   70 pkt[1].; IF[2] = 3.905

[1]Liczba punktów wg Komunikatu Ministra Edukacji i Nauki w sprawie wykazu czasopism naukowych i recenzowanych materiałów z konferencji międzynarodowych z dnia 21 grudnia 2021 roku.

[2]IF – wskaźnik Impact Factor czasopism z roku wydania wg bazy Web of Science

Wykaz skrótów

WPN – Wielkopolski Park Narodowy

PODGiK – Powiatowy Ośrodek Dokumentacji Geodezyjnej i Kartograficznej

HPM – hedoniczny model cen

WLS – regresja ważona metodą najmniejszych kwadratów

DWNP – odległość od Wielkopolskiego Parku Narodowego

GEOPOZ - Zarządu Geodezji i Katastru Miejskiego

$L_{Aeq\ D}$ -wartość równoważonego poziomu dźwięku dla pory dnia

OLS – standardowa metoda regresji najmniejszych kwadratów

HL – determinanta związana z hałasem lotniczym

MTP – miejski transport publiczny

Wartość p – wartość prawdopodobieństwa

Wartość T – wartość testu T-studenta

DB - determinanta związana z dostępnością do przystanku autobusowego

DT – determinanta związana z dostępnością do przystanku tramwajowego

PKP – Polskie Koleje Państwowe

GWR – regresja ważona geograficznie

VIF – współczynnik inflacji wariancji

DRail – zmienna związana z odległością od linii kolejowej

R^2 – współczynnik determinacji

AICc - poprawione kryterium informacyjne Akaikego

GIS – system informacji geograficznej

2. Autoreferat

2.1 Wstęp

Rynek nieruchomości charakteryzuje się szeregiem specyficznych cech, spośród których jedną z ważniejszych ról odgrywa niedoskonałość. Właściwość ta warunkuje m.in. wadliwy mechanizm kształtowania ceny równowagi oraz intensyfikuje zjawiska związane z niską efektywnością oraz znikomą przejrzystością (1-3). W konsekwencji tych prawidłowości uczestnicy rynku mają ograniczony dostęp do informacji o aktualnych trendach panujących w sferze rynkowej (4-6). Ograniczenia z jednej strony dotyczą zarówno samych cen transakcyjnych, ewidencjonowanych zazwyczaj w zamkniętych, niedostępnych dla statystycznego uczestnika rynku bazach danych, a z drugiej strony czynników, które w istotny sposób o tej cenie decydują (7).

Zastosowanie metod statystycznych przy analizach rynku nieruchomości umożliwia uzyskanie perspektywy poznania wielu wiarygodnych informacji dotyczących mechanizmów zachodzących w jego obrębie (8-10). Procedury statystyczne wymagają obszernej bazy danych transakcyjnych, ich zastosowanie pozwala jednak na dokładne wyodrębnienie i wskazanie cech nieruchomości decydujących o cenie (11-13). Dodatkowo metody te mogą również usprawnić proces masowej wyceny oraz szacowania typowych nieruchomości poprzez obniżenie kosztów oraz zobiektywizowanie procesu wyceny. Rezultaty otrzymane w wyniku zastosowania instrumentów statystycznych mogą być ponadto wykorzystywane jako odniesienie dla wycen indywidualnych (14-16).

Czynniki, które wykorzystują rzeczoznawcy w trakcie przygotowania opracowań związanych z wyceną nieruchomości lokalowych mieszkalnych podzielić można na kilka składowych tj. np. lokalizacja, stan techniczny budynku, standard i funkcjonalność lokalu czy usytuowanie lokalu w obrębie budynku (17-19). Współcześnie na znaczeniu zyskuje atrybut będący pochodną lokalizacji definiowany jako tzw. najbliższe sąsiedztwo (20,21). W przypadku lokalizacji kluczowym kryterium poddawanym analizie zazwyczaj jest komunikacja, natomiast w przypadku najbliższego sąsiedztwa podstawowymi czynnikami decydującymi o tym czy dana nieruchomość jest korzystnie usytuowana są cechy związane z: emisją (hałasu, szkodliwych związków chemicznych), sąsiedztwem (miejskie tereny zielone, lasy czy parki narodowe) oraz dostępnością lub jej brakiem do infrastruktury transportowej, usługowej i społecznej (22-24).

Lokalizacja jest istotną cechą z uwagi na to, że nie ma możliwości jej modyfikacji, odmiennie do większości pozostałych cech np. standard wykończenia może zostać podniesiony poprzez wykonanie gruntownego remontu. Sposób oddziaływania atrybutów lokalizacyjnych

wraz z cechami charakteryzującymi najbliższe sąsiedztwo szczególnie w ostatnich latach stanowił jeden z kluczowych elementów badań związanych z charakterystyką rynku nieruchomości (25-28).

Tabela 1 Atrybuty – na podstawie przeglądu literatury

Kategoria	Atrybut
Charakterystyka fizyczna mieszkania	Powierzchnia mieszkania Liczba pomieszczeń Wiek budynku Typ jednostki mieszkaniowej Dostępność parkingu/garażu Lokalizacja na piętrze Konstrukcja budynku Forma własności Dostępność piwnicy Standard wykończenia Efektywność energetyczna
Charakterystyka sąsiedztwa	Odległość do centrum miasta Odległość do szkół Dostępność transportu publicznego Odległość do sklepów Odległość do terenów rekreacyjnych Uciążliwe sąsiedztwo (lotniska, itp.) Odległość do stref przemysłowych
Charakterystyka środowiska	Odległość od jezior Odległość od terenów zielonych, parków Odległość od terenów prawnie chronionych Zanieczyszczenie powietrza Odległość od innych cennych przyrodniczo terenów (np. góry)
Charakterystyka uwarunkowań ekonomicznych	Wielkość podatków Struktura demograficzna Możliwości zatrudnienia Perspektywy rozwoju gospodarczego Wartość generowanych dochodów Stopień rozwoju przedsiębiorstw Występowanie barier planistycznych Wartość współczynników makroekonomicznych

Należy jednocześnie podkreślić, że dla wielu potencjalnych nabywców znacznie istotniejsze niż usytuowanie mieszkania mogą być często inne atrybuty takie jak np. lokalizacja mieszkania na piętrze (29,30). Uczestnicy rynku coraz częściej przywiązują uwagę do prozaicznych zagadnień związanych m.in. z nasłonecznieniem mieszkania (31). Założenie zgodnie z którym to wyłącznie lokalizacja wpływa na cenę jest niewłaściwe. Gdyby powyższa koncepcja była prawidłowa to dwie porównywalne nieruchomości lokalowe usytuowane w jednym budynku w trakcie transakcji osiągnęłyby identyczną cenę. Praktyka natomiast udowadnia, że nawet w sytuacji gdy mieszkania te mają jednakową powierzchnię, to ceny

transakcyjne mogą być rozbieżne z uwagi na różnice w pozostałych atrybutach. Dodatkowo należy zaznaczyć, że jedną z podstawowych cech charakteryzujących nieruchomości niezależnie od rodzaju jest niejednorodność, na skutek której m.in. atrybuty istotne dla jednego typu nieruchomości mogą mieć marginalne znaczenie w przypadku nieruchomości innego typu (32-34). Biorąc pod uwagę powyższe założenia kompleksowe analizy rynku nieruchomości powinny uwzględniać bezwzględnie atrybuty należące do szerokiego spektrum cech.

Podsumowując, cena nieruchomości lokalowych mieszkalnych uzależniona może być od szeregu czynników, które standardowo dzielą się na cztery podstawowe grupy determinant: fizyczne, lokalizacyjne, środowiskowe oraz ekonomiczne (Tab. 1).

2.2 Cel pracy

Głównym celem pracy doktorskiej było sprawdzenie, czy wykorzystanie metod statystycznych umożliwia prognozowanie wielkości oraz charakteru oddziaływania wybranych atrybutów na kształtowanie cen nieruchomości oraz zweryfikowanie czy wykorzystanie tych metod może w pewnym stopniu usprawnić proces wyceny nieruchomości

Cele szczegółowe

1. Celem pierwszego etapu analiz było określenie oddziaływania obszaru prawnie chronionego (Wielkopolski Park Narodowy) na kształtowanie się cen nieruchomości lokalowych mieszkalnych na przykładzie gminy Mosina zlokalizowanej na terenie Parku.
2. Zamierzeniem drugiej części rozprawy doktorskiej było oszacowanie oraz wskazanie sposobu oddziaływania hałasu lotniczego na ceny nieruchomości zabudowanych na terenie Poznania.
3. W trakcie trzeciego etapu analiz przeanalizowany został atrybut związany z Miejskim Transportem Publicznym (MTP). Podstawowym celem tej części rozprawy było ustalenie wielkości oraz charakteru sposobu oddziaływania dostępności do MTP (definiowanego przez dostęp do przystanków autobusowych i tramwajowych) na ceny transakcyjne lokali mieszkalnych w granicach miasta Poznania.
4. Zamierzeniem czwartego etapu analiz było zidentyfikowanie sposobu oddziaływania infrastruktury kolejowej na ceny transakcyjne nieruchomości lokalowych mieszkalnych w granicach administracyjnych jednej z gmin powiatu poznańskiego, tj. gminy Kórnik.
5. Celem piątej części rozprawy było zidentyfikowanie kluczowych atrybutów kształtujących ceny transakcyjne w obrębie rynku mieszkaniowego w Poznaniu. Dodatkowym zadaniem było rozpoznanie oraz wskazanie w obrębie analizowanego obiektu badawczego lokalnych

uwarunkowań związanych ze sposobem oddziaływania wybranych atrybutów, które mogą świadczyć o złożoności i niejednoznaczności lokalnego rynku nieruchomości.

Hipotezy badawcze

W rozprawie doktorskiej sformułowano oraz zweryfikowano następujące hipotezy badawcze:

1. Atrybuty lokalizacyjne, w szczególności cechy związane z najbliższym sąsiedztwem i warunkami środowiskowymi w istotny sposób wpływają na ceny lokali mieszkalnych.
2. Cechy fizyczne lokali mieszkalnych determinują cenę transakcyjną nieruchomości.
3. Wielkość oraz charakter oddziaływania wybranych atrybutów na kształtowanie cen transakcyjnych zdeterminowane są lokalnymi uwarunkowaniami.

Zakres badań

Badania stanowiące podstawę realizowanej rozprawy doktorskiej ze względu na złożoność rynku nieruchomości w swojej strukturze uwzględniały szerokie spektrum zmiennych należących do zdefiniowanych wcześniej grup. Biorąc pod uwagę zdefiniowany cel podstawowy, cele szczegółowe oraz hipotezy badawcze, poszczególne opracowania związane były przede wszystkim z jedną determinantą należącą do szeroko rozumianej grupy cech lokalizacyjnych charakterystyczną dla danego, analizowanego rynku nieruchomości. Zakres realizowanych analiz obejmował kolejno następujące elementy:

1. Określenie charakteru oddziaływania cechy, związanej z charakterystyką środowiska zdefiniowaną przez dostępność, przyjętą jako odległość, do obszaru prawnie chronionego (WPN) na ceny nieruchomości (publikacja nr 1).
2. Określenie sposobu oddziaływania na ceny transakcyjne lokali mieszkalnych lokalizacji w najbliższym sąsiedztwie nieruchomości infrastruktury generującej hałas tj. portu lotniczego (publikacja nr 2).
3. Zdefiniowanie wielkości oraz formy wpływu infrastruktury transportowej (tramwajowej, autobusowej oraz kolejowej) na ceny lokali mieszkalnych (publikacja nr 3 i 4).
4. Sformułowanie w obrębie analizowanych rynków lokalnych uwarunkowań związanych ze sposobem oddziaływania analizowanych atrybutów na ceny transakcyjne lokali mieszkalnych (publikacja nr 4 i 5).

2.3 Wyniki badań

Analizy, których wyniki stanowiły podstawę niniejszej rozprawy doktorskiej, zostały przeprowadzone w pięciu etapach, a ich rezultaty zostały przedstawione w pięciu oryginalnych artykułach naukowych. Najistotniejszym celem każdego z etapów badań było określenie atrybutów istotnych dla analizowanego, lokalnego rynku nieruchomości.

Etap I

Materiały i Metody

Badanie przeprowadzono na podstawie danych źródłowych pozyskanych z Powiatowego Ośrodka Dokumentacji Geodezyjnej i Kartograficznej w Poznaniu (PODGiK). Zbiór danych związany był z transakcjami rynkowymi lokali mieszkalnych, które miały miejsce w obrębie gminy Mosina w latach 2014-2018 r. (1182 transakcji). W skład podstawowych danych zewidencjonowanych w przedmiotowej bazie danych (dla każdej transakcji) należały informacje związane z: lokalizacją, datą transakcji, ceną transakcyjną, powierzchnią (mieszkania), powierzchnią pomieszczeń pomocniczych (np. komórka lub piwnica) oraz informacje o piętrze usytuowania lokalu.

Podstawę zrealizowanych analiz stanowiło uwzględnienie lokalizacji WPN, który znajduje się w obrębie trzech gmin: Mosina, Stęszew oraz Puszczykowo, a jego powierzchnia wynosi 7584 ha. Wokół parku funkcjonuje strefa ochronna, a sumaryczna powierzchnia Parku wraz z otuliną wynosi 14 840 ha. W celu identyfikacji zależności występujących między zmienną zależną (ceną transakcyjną), a zmiennymi niezależnymi (atrybutami) zastosowana została analiza przestrzenna z uwzględnieniem lokalizacji analizowanych lokali mieszkalnych w odniesieniu do położenia WPN oraz analiza statystyczna z wykorzystaniem metody HPM.

Wyniki

Pierwsza część badania polegała na wstępnej weryfikacji dostępności do WPN na ceny lokali mieszkalnych i wykonana została na podstawie analizy przestrzennej, która podzielona została na dwa etapy. W ramach pierwszej części zgromadzone transakcje pogrupowane zostały na dwie grupy: właściwą oraz kontrolną. Pierwszą stanowiły lokale znajdujące się w bezpośrednim sąsiedztwie WPN (bufor 1 km – 395 transakcji), do drugiej grupy należały natomiast pozostałe lokale zlokalizowane powyżej 1 km od granic WPN – 787 transakcji. Podstawowe statystyki opisowe dla zmiennych objaśniających i zmiennej objaśnianej (t.j. średnia oraz odchylenie standardowe) zostały zdefiniowane dla każdej grupy. Należy podkreślić że określenie tych charakterystyk pozwoliło stwierdzić że średnia cena transakcyjna lokali mieszkalnych znajdujących się wewnątrz bufora była wyższa od ceny lokali zlokalizowanych poza wyznaczoną strefą.

Drugi etap analizy zmienności przestrzennej przeprowadzony został w oparciu o podział analizowanych transakcji na 6 grup. Podstawowym celem sklasyfikowania materiału badawczego na 6 grup było uszczegółowienie początkowej analizy oraz przedstawienie zmian cen transakcyjnych w poszczególnych grupach. Klasyfikacja została wykonana na podstawie odległości do granic WPN. Przyjęto następujące kryteria klasyfikacji: <0,50 km, 0,50-0,75 km, 0,75-1,00 km, 1,00-1,25 km, 1,25-1,50 km, >1,50 km. Biorąc pod uwagę powyższe założenie, statystyki opisowe (t.j. średnia oraz mediana cen transakcyjnych) zaprezentowano dla każdej grupy. Mediana cen lokali mieszkalnych w analizowanych grupach wyznaczonych w oparciu o kryterium odległościowe zmieniała się wyraźnie w badanym zbiorze danych transakcyjnych. Zdecydowanie wyższe ceny odnotowane zostały w dwóch pierwszych grupach znajdujących się w bezpośrednim sąsiedztwie WPN, a wraz ze wzrostem odległości od WPN mediana cen transakcyjnych była wyraźnie niższa.

Należy podkreślić że analiza przestrzenna umożliwia obserwację wstępnych zależności między ceną transakcyjną, a dostępnością do WPN. Nie można jednak na jej podstawie formułować istotnych wniosków o wpływie dostępności do WPN na cenę, ponieważ analiza ta nie uwzględnia w swojej strukturze pozostałych atrybutów, które w istotny sposób mogą determinować cenę lokalu mieszkalnego w obrębie lokalnego rynku nieruchomości.

W związku z powyższym w drugiej części badania przeprowadzona została analiza statystyczna z wykorzystaniem HPM, techniki WLS. Do cech lokali mieszkalnych analizowanych w badaniu należały oprócz cechy związanej z dostępnością do WPN atrybuty związane z charakterystyką: lokalu mieszkalnego (powierzchnia, piętro, wysokość budynku), lokalizacji (dostępność komunikacji, dostęp do szkół, dostęp do terenów prawnie chronionych, odległość od centrum Mosiny, odległość od Poznania). W modelu dodatkowo uwzględniona została cecha związana z rokiem transakcji. Wybór zdefiniowanych zmiennych wynikał przede wszystkim z dostępności danych oraz charakterystyki lokalnego rynku nieruchomości. Estymowany model był dobrze dopasowany, ponieważ wyjaśniał około 74% wahań cen. Większość zmiennych zastosowanych w modelu okazała się istotna statystycznie. Przewidywane znaki poszczególnych współczynników były zgodne z oczekiwanymi.

Na podstawie przeprowadzonej analizy statystycznej zaobserwowano, że cechy związane z lokalizacją miały istotny wpływ na ceny transakcyjne lokali mieszkalnych. Wzrost odległości od Poznania skutkował zmniejszeniem cen transakcyjnych. Z drugiej jednak strony lokale mieszkalne, które były zlokalizowane w ścisłym centrum Mosiny odnotowywały niższe ceny, od tych położonych w innych częściach gminy. Otrzymane wyniki mogą potwierdzać

preferencje uczestników rynku związane z zamieszkaniem w spokojniejszej okolicy, która jednocześnie jest dobrze skomunikowana z dużym ośrodkiem miejskim.

Biorąc pod uwagę cel opracowania, istotny był wpływ dostępności do WPN na cenę lokalu mieszkalnego. Wykorzystanie funkcji regresji hedonicznej umożliwiło określenie współczynnika zmiany ceny lokalu mieszkalnego w odniesieniu do zmiany odległości mieszkania od odległości do granic WPN. Współczynnik dla cechy DWNP otrzymał wartość -0,126 co oznacza, że porównywalny lokal zlokalizowany w większej odległości (1 km) od granic do WPN średnio osiągał na rynku niższą ceną średnio o 12,6 % od lokalu, który znajdował się w bliższej odległości. Zastosowanie modelu WLS potwierdziło wnioski uzyskane w trakcie przeprowadzonej analizy przestrzennej.

Uzyskane wyniki w obrębie lokalnego rynku wskazują na pozytywny wpływ analizowanego atrybutu na ceny transakcyjne analizowanych nieruchomości, co może świadczyć o tym, że przeciętni uczestnicy rynku uwzględniają czynniki związane z dostępnością do terenów sprzyjających rekreacji i umożliwiających aktywny wypoczynek.

Publikacja

Chwiałkowski, C.; Zydroń, A. Socio-Economic and Spatial Characteristics of Wielkopolski National Park: Application of the Hedonic Pricing Method. Sustainability 2021, 13, 5001. https://doi.org/10.3390/su13095001

Etap II

Materiały i Metody

Niniejsza część badań przeprowadzona została na podstawie dwóch podstawowych grup danych źródłowych. Pierwszą, zasadniczą grupę stanowiły dane transakcyjne pozyskane z GEOPOZ-u w Poznaniu. W celu określenia wpływu hałasu lotniczego (rozumianego poprzez położenie nieruchomości w strefie ograniczonego użytkowania) na ceny mieszkań, w pracy zewidencjonowano łącznie 1550 transakcji lokali mieszkalnych na terenie miasta Poznania w obrębach ewidencyjnych, w których występowała strefa ograniczonego użytkowania. Dane te dotyczyły transakcji zawartych od pierwszego do czwartego kwartału 2020 roku.

Drugą grupę danych źródłowych stanowiły natomiast informacje pochodzące z mapy hałasu miasta Poznania z 2017 roku. Były to dane bezpośrednio związane z hałasem lotniczym występującym na terenie obszarów ograniczonego użytkowania lotnisk: Poznań-Ławica oraz Poznań-Krzesiny.

Obszar ograniczonego użytkowania lotniska Poznań-Ławica zlokalizowany jest na terenie miasta Poznań oraz gminy Tarnowo Podgórne. Obszar ten wprowadzony został uchwałą nr XVIII/302/12 Sejmiku Województwa Wielkopolskiego z dnia 30.01.2012 r. (35). Wytyczony

został na podstawie: monitoringu hałasu, danych operacyjnych, danych prognostycznych, rozkładu trajektorii lotów oraz informacji technicznej o samolotach operujących na lotnisku. W strefie wewnętrznej zlokalizowanych było około 1100 nieruchomości mieszkalnych oraz 10 budynków użyteczności publicznej. W strefie zewnętrznej natomiast znajdowało się około 2300 nieruchomości mieszkalnych (w tym 800 lokali mieszkalnych) oraz 11 budynków użyteczności publicznej. Obszar ten podzielony został na dwie strefy (wewnętrzną i zewnętrzną): obszar ograniczonego użytkowania dla zabudowy mieszkaniowej oraz obszar ograniczonego użytkowania dla terenów o podwyższonych wymaganiach akustycznych.

Obszar ograniczonego użytkowania dla lotniska wojskowego Poznań-Krzesiny określony został w Rozporządzeniu nr 40/07 Wojewody Wielkopolskiego z dnia 31 grudnia 2007 r. (36). Obszar podzielony został na trzy strefy, w obrębie których występują ściśle zdefiniowane wymagania dotyczące m.in. przeznaczenia terenu, sposobu wykorzystania terenu oraz wymogów technicznych budynków. Strefa I znajduje się na terenie: Poznania oraz gmin Luboń, Komorniki i Kórnik. Strefa II swoim zasięgiem obejmuje natomiast miasto Poznań oraz gminy: Luboń, Kórnik, Mosina oraz Komorniki. Strefa III obejmuje zdecydowanie największy obszar, w skład którego wchodzą gminy: Luboń, Komorniki, Puszczykowo, Stęszew, Mosina, Kórnik, Kleszczewo oraz Środa Wielkopolska wraz z miastem Poznań.

W strefie I obejmującej tereny zlokalizowane w bezpośrednim sąsiedztwie lotniska zabrania się przeznaczania terenów pod zabudowę przez: budynki mieszkalne, szpitale, szkoły, przedszkola itp. Jednocześnie w strefie tej niemożliwa jest zmiana funkcji istniejących obiektów, które nie wymagają ochrony akustycznej na budynki podlegające ochronie akustycznej. Zmiana funkcji budynków istniejących lub zagwarantowanie właściwego klimatu akustycznego jest możliwa z wykorzystaniem przegród budowlanych o niezbędnej izolacyjności akustycznej. Na terenie strefy II występują zdecydowanie mniejsze restrykcje związane z przeznaczeniem czy sposobem wykorzystania nieruchomości. Dopuszczalna jest zabudowa mieszkaniowa, niemożliwe natomiast jest podobnie jak w przypadku strefy I, przeznaczanie terenów na budowę szpitali czy budynków związanych ze stałym pobytem dzieci oraz młodzieży. Wymieniona zabudowa mieszkaniowa może być lokalizowana w strefie II przy zapewnieniu odpowiedniego klimatu akustycznego w pomieszczeniach podlegających ochronie akustycznej. Na obszarze strefy III nie występują ograniczenia w kontekście przeznaczenia terenów, a zabudowa każdego rodzaju może być lokalizowana pod warunkiem zapewnienia odpowiedniego klimatu akustycznego w pomieszczeniach wymagających specjalnej ochrony.

Wyniki zostały opracowane na podstawie analizy przestrzennej i analizy statystycznej zrealizowanej metodą HPM. Kluczowy aspekt przeprowadzonych badań związany był z lokalizacją transakcji, które podzielone zostały na dwie grupy: nieruchomości znajdujące się wewnątrz stref ograniczonego użytkowania obu lotnisk wyznaczonych według spójnego kryterium ($L_{Aeq\ D}$ powyżej 55 dB) oraz nieruchomości znajdujące się na zewnątrz strefy ograniczonego użytkowania ($L_{Aeq\ D}$ poniżej 55 dB).

Wyniki

Wyselekcjonowany zbiór danych w pierwszej kolejności wykorzystany został do wstępnej analizy na potrzeby której podzielone zostały na dwie wymienione wyżej grupy. W granicach miasta Poznania zidentyfikowanych zostało pięć obrębów ewidencyjnych (Górczyn, Grunwald, Jeżyce, Łazarz oraz Sołacz), w których w analizowanym okresie czasu zawarta została przynajmniej jedna transakcja w dwóch wyodrębnionych grupach. W celu określenia wstępnych zależności między ceną transakcyjną, a lokalizacją lokalu mieszkalnego względem portu lotniczego w wymienionych osiedlach określona została mediana cen (przy uwzględnieniu przynależności nieruchomości do danej grupy). W każdym z analizowanych obrębów mediana cen transakcyjnych nieruchomości była zdecydowanie niższa wśród nieruchomości położonych w strefie ograniczonego użytkowania w porównaniu do tych położonych poza strefą. W skrajnym przypadku (obręb Łazarz) różnica mediany cen pomiędzy grupami osiągnęła 15.85%.

W celu określenia sposobu oddziaływania wybranych atrybutów zastosowano wieloczynnikową analizę funkcji ceny, w analizie wykorzystana została HPM, technika OLS. W badaniu wykorzystano następujące zmienne: lokalizacja, sąsiedztwo, forma własności, położenie na piętrze, powierzchnia oraz hałas lotniczy. Różnica pomiędzy wartościami obserwowanymi, a zmienną zależną określona przez błąd standardowy wyniosła 0,2468, przy 1528 stopniach swobody. Na podstawie przeprowadzonych analiz można stwierdzić, że w badanym okresie czasu na ceny lokali mieszkalnych istotny wpływ miało ich położenie w określonych dzielnicach Poznania. Lokalizacja w dzielnicach Sołacz, Stare Miasto i Winiary miało szczególne znaczenie dla wzrostu cen. Ponadto, analizując wyniki, można stwierdzić, że na cenę transakcyjną istotnie wpływało jej najbliższe sąsiedztwo oraz lokalizacja na wyższym piętrze. Przechodząc do najistotniejszej części analizy, zmienna objaśniająca HL była istotna statystycznie. Otrzymany model umożliwił identyfikację procentowej zmiany różnicy cen nieruchomości o porównywalnych cechach, położonych na terenie narażonym na hałas powyżej 55 dB, jak i poniżej tej wartości. Współczynnik cechy HL przyjął wartość -0,04578, co wskazuje, że lokale narażone na hałas lotniczy średnio przyjmują wartość niższą niż 4,58%,

w porównaniu do nieruchomości położonych poza strefą oddziaływania strefy oddziaływania lotniska.

Publikacja

Chwiałkowski, C.; Zydroń, A. The Influence of Aircraft Noise on the Prices of Residential Properties on the Example of Poznań Rocznik Ochrona Środowiska 2021, 23, 263-278. https://doi.org/10.54740/ros.2021.017

Etap III

Materiały i Metody

Podstawową grupą danych stanowiących podstawę badania były dane źródłowe pozyskane z GEOPOZ-u w Poznaniu. Dane te związane były z transakcjami rynkowymi lokali mieszkalnych, które zostały zawarte w obrębie miasta Poznania w 2020 r. (2561 transakcji). Zgromadzone dane transakcyjne z uwagi na fakt że pochodziły z aktów notarialnych stanowiły rzetelne oraz wiarygodne źródło informacji o aktualnej sytuacji na rynku nieruchomości. Charakterystyka tego typu danych sprawia, że mogą one znaleźć szerokie zastosowania podczas różnorodnych analiz rynku nieruchomości.

Biorąc pod uwagę cel prowadzonych analiz szczególną rolę podczas wykonanych badań pełniła ponadto miejska infrastruktura transportowa. Zgodnie z przeprowadzoną inwentaryzacją na koniec 2017 r. sumaryczna długość linii komunikacyjnych autobusowych wyniosła 1872,70 km (1118,14 km w obrębie miasta oraz 754,56 km na terenie aglomeracji). Całkowita długość wszystkich linii tramwajowych równa była 229,33 km, długość dostępnych tras tramwajowych wyniosła natomiast 68,85 km. Z punktu widzenia charakterystyki prowadzonych analiz istotniejsza była jednak lokalizacja przystanków miejskiego transportu publicznego. W obrębie miasta Poznania zlokalizowanych było w trakcie przeprowadzonej inwentaryzacji 1162 przystanków autobusowych, 239 tramwajowych oraz 52 przystanki tramwajowo-autobusowe. W celu identyfikacji analizowanych zależności dane wejściowe poddane zostały analizie przestrzennej oraz analizie statystycznej. Najistotniejsza część analiz została przeprowadzona za pomocą modelu HPM – OLS oraz WLS.

W pierwszej kolejności zgromadzone dane poddano wstępnej weryfikacji opartej o analizę przestrzenną, której podstawowym założeniem było zdefiniowanie przestrzennych prawidłowości względem analizowanego atrybutu. Biorąc pod uwagę sposób charakterystyki badanej cechy (przystanki autobusowe oraz przystanki tramwajowe) wstępna część analiz podzielona została na dwie grupy.

Na początek uwzględniona została dostępność do przystanków autobusowych. Transakcje przyjęte do analizy zaklasyfikowano do 6 grup zdefiniowanych na podstawie odległości jaką

należy przejść z danego lokalu mieszkalnego do przystanku tego typu. Biorąc pod uwagę regularną strukturę rozmieszczenia przystanków autobusowych w Poznaniu przyjęto następujące kryteria klasyfikacji: <100 m, 100-200 m, 200-300 km, 300-400 m, 400-500 m, >500 m. Mediana cen lokali mieszkalnych w wyznaczonych na podstawie kryterium odległości grupach, ulegała istotnym zmianom w ocenianym zbiorze danych transakcyjnych i osiągnęła najniższą wartość w ostatniej grupie. Drugi etap tej części analiz wykonany został w analogiczny sposób, różnicę stanowiła jedynie metoda interpretacji dostępności komunikacyjnej definiowanej przez odległość do przystanków tramwajowych. Z uwagi na inną strukturę rozmieszczenia oraz liczebność przystanków tramwajowych przyjęte kryteria klasyfikacji zostały zmodyfikowane i sformułowane w następującej formie: <200 m, 200-400 m, 400-600 km, 600-800 m, 800-1000 m, >1000 m. Mediana cen lokali mieszkalnych w analizowanych grupach znajdowała się w przedziale od 6750 zł/m^2 do 7150 zł/m^2 i osiągnęła największą wartość w pierwszej grupie tj. nieruchomości zlokalizowanych w odległości do 200 m od przystanku tramwajowego.

Mając na uwadze podstawowy cel prowadzonego badania w trakcie analizy statystycznej do modelu przyjęto cechę związaną z dostępnością komunikacyjną definiowaną przez dwie zmienne: odległość do przystanku tramwajowego oraz odległość do przystanku autobusowego. Ponadto do charakterystycznych cech analizowanych w przedmiotowym badaniu należały cechy fizyczne lokalu mieszkalnego (liczba pomieszczeń, powierzchnia, piętro oraz dostępność pomieszczenia przynależnego) oraz atrybuty związane z lokalizacją jednostki mieszkaniowej (dostęp do: szkół, miejskich terenów zielonych, centrum Poznania, centrum handlowego oraz rzeki Warta).

Analiza przeprowadzona została w dwóch wariantach regresji: OLS oraz WLS. Dopasowanie modeli, zdefiniowane współczynnikiem determinacji, było wyraźnie zróżnicowane OLS – 52%, a WLS – 70%. Zarówno w modelu OLS, jak i WLS większość zmiennych przyjętych do modelu była istotna statystycznie. Różnica pomiędzy dwoma modelami wystąpiła jedynie w przypadku zmiennej związanej z odległością nieruchomości od miejskich terenów zielonych, która w modelu OLS przy wartościach $p \leq 0.05$ okazała się statystycznie istotna. Z obydwu modeli wykluczone zostały zmienne związane kolejno z lokalizacją lokalu mieszkalnego na parterze, pierwszym lub drugim piętrze oraz z liczbą pomieszczeń (do dwóch pomieszczeń) z uwagi na brak zróżnicowania zmienności w analizowanej bazie danych.

Na podstawie estymowanego modelu techniką WLS można wnioskować, że jedna z dwóch najistotniejszych zmiennych tj. cecha DB okazała się nieistotna statystycznie (wartość p =

0.718). Bezpośrednią przyczyną tego stanu rzeczy może być regularna struktura rozmieszczenia przystanków autobusowych w obrębie Poznania co może skutkować tym, że dla zdecydowanej większości lokali mieszkalnych przystanek taki znajduje się w najbliższym sąsiedztwie (spośród 2561 transakcji włączonych do analizy jedynie 109 mieszkań było zlokalizowanych w odległości większej od 500 m). Na skutek porównywalnej dostępności infrastruktura tego typu może nie pełnić kluczowej roli w trakcie podejmowania decyzji inwestycyjnych przez uczestników rynku nieruchomości. Atrybut DT był natomiast kluczowy z punktu widzenia funkcjonowania mechanizmów rynkowych. Na podstawie wartości współczynnika regresji dla tej cechy możemy wnioskować, że spośród dwóch porównywalnych lokali wyraźnie wyższą cenę jednostkową (około 15% na 1 km) osiągał lokal zlokalizowany w mniejszej odległości od tego typu przystanku.

Publikacja

Chwiałkowski, C.; Zydroń, A. The Impact of Urban Public Transport on Residential Transaction Prices: A Case Study of Poznań, Poland. ISPRS Int. J. Geo-Inf. 2022, 11, 74. https://doi.org/10.3390/ijgi11020074

Etap IV

Materiały i Metody

Analizy zostały zrealizowane na podstawie danych źródłowych pochodzących z PODGiK-u w Poznaniu. Analizowany materiał źródłowy obejmował 737 rynkowych transakcji lokali mieszkalnych, które zostały zawarte w obszarze gminy Kórnik w latach 2019-2021. Struktura przedmiotowej bazy danych pozwala na zgromadzenie informacji o podstawowych charakterystykach związanych z każdą zewidencjonowaną nieruchomością. Istotnym, elementarnym problemem tego typu bazy danych jest brak komplementarności względem szczegółowej charakterystyki podstawowych atrybutów wpływających na cenę nieruchomości takich jak np. najbliższe otoczenie, stan techniczny budynku bądź standard wykończenia mieszkania. W celu zminimalizowania negatywnych skutków tej sytuacji do badań włączone zostały również zmienne scharakteryzowane na podstawie analiz własnych (np. Odległość do najbliżeszego przystanku autobusowego).

Przez teren gminy Kórnik (powierzchnia gminy - 186,6 km^2, liczba ludności - 31 451 osób) przebiega jedna linia kolejowa nr 272 Kluczbork – Poznań Główny. Natężenie ruchu pociągów na tej linii kolejowej jest umiarkowane, w ciągu tygodnia (od poniedziałku do piątku) średnio odbywają się 23 kursy na trasie Kórnik - Poznań, a w weekendy natężenie jest mniejsze (17 kursów). Zarządcą linii są PKP Polskie Linie Kolejowe, a jej trasa wynosi 200,90 km i przechodzi przez dwa województwa: opolskie oraz wielkopolskie. Warto zaznaczyć, że jest

to linia w całości zelektryfikowana, dwutorowa o szerokości 1435 mm, a maksymalna prędkość w przypadku pociągów pasażerskich na poszczególnych odcinkach trasy wynosi 120 km/h.

Z punktu widzenia wykonywanych analiz niezwykle istotna była szczegółowa lokalizacja linii, która przebiega w północnej części gminy przez obręby ewidencyjne: Pierzchno, Runowo, Szczodrzykowo, Borówiec, Robakowo, Gądki oraz Koninko. Dodatkowo, należy zaznaczyć, że na terenie obszaru badań znajdują się trzy przystanki związane z transportem kolejowym: Pierzchno (przystanek osobowy i posterunek odgałęźny), Kórnik (przystanek osobowy) oraz Gądki (stacja).

Identyfikacja sposobu oddziaływania wybranych zmiennych niezależnych na ceny transakcyjne została zrealizowana na podstawie analizy statystycznej, której fundament stanowiły metody regresji OLS oraz GWR. Podstawową różnicę pomiędzy zastosowanymi technikami stanowi prawidłowość, zgodnie z którą współczynniki w modelu globalnym w skali analizowanego obiektu (OLS) są stałe, natomiast współczynniki w modelu lokalnym (GWR) są zmienne oraz w najistotniejszym stopniu zależą od lokalizacji.

Wyniki

Włączone do badania zmienne niezależne w pierwszej kolejności zostały poddane wstępnej analizie, która związana była z niezwykle często występującymi problemami przy tego typu rozważaniach tzn. ze zjawiskiem współliniowości między przyjętymi cechami oraz zjawiskiem skośności będącej miarą asymetrii analizowanych obserwacji. W rezultacie atrybuty charakteryzujące się wartością skośności większą niż 3 zostały przetransformowane logarytmicznie. Następnie estymowana została regresja OLS za pomocą, której obliczone zostały wartości VIF dla analizowanych atrybutów. Z ostatniej części analizy wykluczone zostały atrybuty o wartości VIF większej niż 7,5.

W rezultacie zastosowania modelu regresji globalnej OLS można wnioskować, że większość zmiennych włączonych do modelu była statystycznie istotna przy wartości $p \leq 1\%$. Zmienne nieistotne ze statystycznego punktu widzenia to: liczba pomieszczeń, odległość do wód powierzchniowych, odległość od szkół oraz odległość do najbliższej drogi głównej lub drugorzędnej. Uzyskany model wyjaśniał około 55% zmienności obserwowanego zjawiska. Biorąc pod uwagę współczynnik dla cechy najistotniejszej z punktu widzenia zdefiniowanego celu pracy tzn. dla zmiennej DRail można wnioskować, że ceny nieruchomości zlokalizowanych w bliższej odległości od linii kolejowej są relatywnie mniejsze względem cen porównywalnych nieruchomości zlokalizowanych w większej odległości w odniesieniu do tego atrybutu. Pod względem procentowym natomiast różnica cen na skutek zmiany odległości

nieruchomości względem linii kolejowej jest niewielka i wynosi 0,5% (cena składowa dla atrybutu Drail zmienia się o 0,5% wraz ze zmianą odległości o 1 m).

Rezultaty otrzymane na skutek zaimplementowania regresji GWR wskazują na nieznaczną różnicę w zakresie otrzymanych wyników w odniesieniu do regresji OLS. Dla analizowanej grupy badawczej w przypadku regresji GWR parametry charakteryzujące dokładność modelu osiągnęły: wartość skorygowanego R^2 - 0,5724 (OLS: 0,5571), a wartość AICc – 2068,15 (OLS: - 2045,25). Bezpośrednie porównanie tych wartości może wskazywać na to, że model estymowany metodą regresji ważonej geograficznie dla analizowanej grupy danych charakteryzuje się minimalnie większą adekwatnością.

Ze względu na strukturę metoda regresji GWR umożliwia oszacowanie zmiennych współczynników zarówno w miejscu występowania samych obserwacji jak i w każdym, innym dowolnym miejscu analizowanego obszaru nawet w przypadku gdy nie zarejestrowano tam żadnych danych. Estymowane, lokalne współczynniki dla zmiennej związanej z infrastrukturą kolejową charakteryzowały się wyraźnym zróżnicowaniem i oscylowały w zakresie od 0,000020 do 0,000054. Zasadniczo, z kilkoma wyjątkami obserwacje znajdujące się w północnej części gminy oraz zlokalizowane w pobliżu trasy linii kolejowej charakteryzowały się mniejszymi wartościami współczynnika.

Wzorzec przestrzennego rozmieszczenia współczynników dla cechy Drail w obrębie gminy Kórnik wskazywał na silny, negatywny wpływ tego atrybutu na ceny lokali mieszkalnych (mniejsza wartość współczynnika) w północnej części gminy znajdującej się w pobliżu linii kolejowej. Dla centralnej części gminy na terenie, której znajduje się m.in. miasto Kórnik wartość współczynnika jest wyraźnie wyższa, co świadczy o tym że zwiększenie odległości od linii kolejowej w zdecydowanie większym stopniu wpływa na wzrost jednostkowej ceny lokali mieszkalnych w odniesieniu do pozostałych obszarów gminy Kórnik.

Publikacja

Chwiałkowski, C.; Zydroń, A. Influence of Railroad Infrastructure on Residential Property Prices on the Example of Kórnik Municipality Rocznik Ochrona Środowiska 2022, 24, 54-73. https://doi.org/10.54740/ros.2022.005

Etap V

Materiały i Metody

Analiza stanowiąca podstawę niniejszej części rozprawy doktorskiej została przeprowadzona na podstawie danych źródłowych pozyskanych z GEOPOZ-u w Poznaniu. Wyselekcjonowany zbiór danych składał się z 6611 transakcji nieruchomości lokalowych

mieszkalnych zawartych od początku stycznia 2019 roku do początku marca 2022 r. Zdecydowana większość transakcji została zawarta w osiedlach znajdujących się w centralnej części miasta np. Łazarz, Jeżyce oraz Stare Miasto oraz częściowo w północnej części miasta Poznania (osiedle: Piątkowo oraz Naramowice).

Analiza statystyczna stanowiła kluczowy element w procesie identyfikacji sposobu wpływu wybranych atrybutów na ceny transakcyjne lokali mieszkalnych. Biorąc pod uwagę cel realizowanego badania analiza ta została przeprowadzona przy uwzględnieniu metody, która umożliwia określenie lokalnych mechanizmów zachodzących na płaszczyźnie rynkowej – regresji GWR. Metoda regresji globalnej w obrębie analizowanego rynku (OLS) ze względu na swoją strukturę stanowiła jedynie punkt wyjściowy do dalszych rozważań. Podstawowa różnica zastosowanych metod polega na tym, że w modelu globalnym parametry są przyjmowane jako stałe, natomiast model w oparciu o GWR rozpoznaje zróżnicowanie przestrzenne tych parametrów. Niezwykle ważnym etapem podczas wykonywania regresji GWR jest kalibracja równania w trakcie której przyjmuje się założenie, zgodnie z którym dane obserwowane w pobliżu lokalizacji danego punktu w większym stopniu oddziałują na estymację określonych współczynników w odniesieniu do obserwacji zlokalizowanych w większej odległości. Parametry estymowanego modelu z wykorzystaniem techniki GWR są szacowane lokalnie z wykorzystaniem metody ważenia najmniejszych kwadratów, co w konsekwencji prowadzi do tego, że dane bliższe mają większe znaczenie w odniesieniu do dalszych obserwacji.

Wyniki

Wstępny etap analiz związany był z syntetyczną charakterystyką zarówno zmiennej zależnej jak i zmiennych niezależnych (uwzględnionych w analizie przede wszystkim na podstawie informacji z biur obrotu nieruchomościami), w ramach której określone zostały podstawowe statystyki opisowe t.j. wartość średnia, odchylenie standardowe oraz wartości maksymalne i minimalne. Charakterystyka ta była ponadto związana z dokładnym sprawdzeniem zjawiska współliniowości między zmiennymi (dla żadnego z atrybutów zjawisko to nie zostało zidentyfikowane) oraz zjawiska skośności w związku z którym trzy zmienne zostały przetransformowane logarytmicznie (odległość do parków, odległość do przystanków autobusowych oraz odległość do centrów handlowych).

Wyniki otrzymane w rezultacie zastosowania regresji globalnej OLS wskazały na to, że większość zmiennych była statystycznie istotna przy wartości $p \leq 1$ %. Zmienne nieistotne ze statystycznego punktu widzenia to: numer piętra, odległość do centrum handlowego oraz odległość do parku. Uzyskany model wyjaśniał około 23% zmienności obserwowanego

zjawiska. Większość zmiennych otrzymała spodziewane wartości współczynników, wyjątkiem może być cecha związana z odległością lokalu mieszkalnego od przystanku tramwajowego. Negatywny wpływ tego atrybutu może być związany z hałasem generowanym przez tego rodzaju środek transportu. Przeprowadzona analiza regresji OLS umożliwiła ponadto określenie na podstawie zbudowanego modelu cen estymowanych analizowanych nieruchomości lokalowych mieszkalnych. Zdecydowana większość wartości standaryzowanych reszt wskazujących na różnice pomiędzy cenami obserwowanymi, a estymowanymi znajdowała się w przedziale -0.5 do 0.5 (2868 obserwacji). W skrajnych przypadkach wartości reszt standaryzowanych wyniosły -3.13 (różnica pomiędzy ceną obserwowaną, a estymowaną wyniosła -4649.13 PLN) oraz 6.38 (różnica między ceną obserwowaną, a estymowaną wyniosła - 9444.06 PLN).

Wyniki uzyskane dla regresji GWR wskazują na istotną pozytywną różnicę w jakości modelowania w porównaniu do regresji globalnej. Wartość skorygowanego R^2 wyniosła 0,477 (OLS: 0,2316), a wartość AICc 15597,432 (OLS: 17035,3480). Biorąc pod uwagę specyfikę tego rodzaju regresji określona została ponadto liczba obserwacji (definiowana przez wartość procentową), które są statystycznie istotne na podstawie wartości T (wartość krytyczna równa była 3.384). Największa liczba istotnych statystycznie obserwacji zdefiniowana została dla cechy powierzchnia lokalu mieszkalnego (10.88%), najmniejsza natomiast określona została dla cechy odległość do wód powierzchniowych (2.24%). Dodatkowo zidentyfikowane zostało również zjawisko współliniowości atrybutów dla każdej pojedynczej obserwacji. Największą liczbę przypadków z wartością VIF większą od 7.5 zidentyfikowano dla zmiennej odległość od miasta Poznania (6178 obserwacji), dla cechy numer piętra natomiast wszystkie obserwacje miały wartość VIF mniejszą od 7.5.

Model uzyskany za pomocą regresji GWR wskazał, że w najistotniejszą determinantą cen transakcyjnych dla rynku lokali mieszkalnych w Poznaniu jako całości była zmienna związana z powierzchnią użytkową mieszkania. Istotność tej zmiennej została potwierdzona dla 719 obserwacji. Atrybut ten miał zgodnie z oczekiwaniami negatywny wpływ na wartość jednostkowej ceny transakcyjnej mieszkań na prawie całym analizowanym obszarze, najsilniejszy negatywny wpływ natomiast zaobserwowano wśród transakcji zlokalizowanych w południowo-wschodniej części miasta. Ujemna korelacja między analizowanym atrybutem, a ceną zmniejszała się natomiast w centrum oraz północno-wschodniej części miasta, gdzie w wybranych rejonach można było zaobserwować pozytywny wpływ analizowanej zmiennej niezależnej na zmienną zależną. Zjawisko to obserwowane jest m.in. w dzielnicy Poznań – Stare Miasto, która uważana jest m.in. z uwagi na lokalizację jako prestiżowa lokalizacja.

W badanym przypadku fakt ten mógł bezpośrednio skutkować wzrostem motywacji do zapłacenia wyższej ceny przez nabywców za każdy dodatkowy metr kwadratowy powierzchni lokalu mieszkalnego. Jednocześnie należy jednak podkreślić, że w wielu przypadkach dodatnia korelacja była nieistotna statystycznie co bezpośrednio skutkuje tym, że opisane wyżej zależności nie mogą być uznane jako niezaprzeczalnie pewne.

Spośród cech lokalizacyjnych interesujące wyniki zaobserwowano dla determinanty związanej z odległością od przystanku autobusowego. Liczba obserwacji istotnych statystycznie była niewielka (161), natomiast jeżeli cecha była istotna to w większości przypadków w lokalizacjach znajdujących się w znacznej odległości od centrum miasta. Zależność ta może świadczyć o tym, że atrybut ten był szczególnie istotny dla nabywców lokali mieszkalnych, którzy w przyszłości będą musieli korzystać z komunikacji miejskiej w celu sprawnego połączenia z centrum. Dla porównania zmienna związana z dostępnością do przystanku tramwajowego była istotna statystycznie dla 315 obserwacji zlokalizowanych w centrum miasta, w większości przypadków wzdłuż przebiegu istniejących linii tramwajowych.

Wartości parametrów modelu GWR, wskazują, że charakter oddziaływania większości atrybutów jest porównywalny do oszacowań modelu OLS, należy jednak podkreślić jak istotne są wartości minimalne oraz maksymalne współczynników, które wskazują jak znacznie może być zróżnicowany sposób oddziaływania danego atrybutu w obrębie analizowanego obszaru. Uzyskane wyniki potwierdzają niejednorodność i złożoność badanego rynku, oraz podkreślają zasadność uwzględnienia w analizie dokładnej lokalizacji geograficznej obserwacji.

Publikacja

Chwiałkowski, C.; Zydroń, A.; Kayzer, D. Assessing the Impact of Selected Attributes on Dwelling Prices Using Ordinary Least Squares Regression and Geographically Weighted Regression: A Case Study in Poznań, Poland. Land 2023, 12, 125. https://doi.org/10.3390/land12010125

2.4 Podsumowanie i wnioski

Badania, których rezultaty zaprezentowano w niniejszej rozprawie doktorskiej, uzupełniają oraz poszerzają dotychczasową wiedzę praktyczną i teoretyczną na temat sposobu oddziaływania analizowanych atrybutów na ceny transakcyjne. W badaniach wykorzystane zostały metody analiz statystycznych zawierających HPM. Istotną rolę spełniły ponadto analizy przestrzenne, które umożliwiły identyfikację uwarunkowań lokalizacyjnych analizowanych

cen nieruchomości oraz pozwoliły określić przestrzenne zależności między ceną, a analizowanymi zmiennymi niezależnymi.

Należy zauważyć, że nieruchomości są dobrem o szczególnym znaczeniu. Cena nieruchomości może zależeć od kilku cech, które są typowe dla lokalnego charakteru rynku nieruchomości. Wszelkiego rodzaju analizy dotyczące rynku nieruchomości powinny być prowadzone kompleksowo. Dodatkowo, sposób oddziaływania wybranych atrybutów może być różny w zależności od rodzaju i zasięgu przestrzennego rynku nieruchomości. Prowadząc analizy rynku nieruchomości, należy mieć również świadomość, że wpływ istotnych czynników na ceny może zmieniać się w czasie oraz zależy od zmian w lokalnych uwarunkowaniach planistycznych, społecznych, gospodarczych i politycznych.

W ramach lokalnego analizowanego rynku nieruchomości stwierdzono, że dostępność do WPN była istotnym atrybutem, pozytywnie wpływającym na ceny nieruchomości (podwyższającym ceny). Podkreślić należy jednak, iż uzyskane wyniki były właściwie uzasadnione, istnieją pewne ograniczenia zastosowanej metody wynikające przede wszystkim z braku komplementarności zbioru danych. W kontekście nieruchomości lokalowych mieszkalnych, jedną z ważniejszych cech wydaje się być standard wykończenia lokalu. W ramach prowadzonych badań, na żadnym z etapów nie było jednak technicznej możliwości włączenia tej zmiennej do modelu ze względu na brak tego typu informacji w dostępnych źródłach danych.

Determinanta związana z hałasem lotniczym w obrębie analizowanego rynku, stanowiła istotny atrybut wpływający na obniżenie cen transakcyjnych. Biorąc pod uwagę zastosowaną metodykę, ograniczenie wykorzystanej metody może być bezpośrednio związane z aktualnością zbioru danych. Mapa akustyczna, która była podstawą wykonanych badań standardowo jest sporządzana w perspektywie pięcioletniej. W związku z tym analizy zostały wykonane zgodnie z dostępnymi materiałami (mapa akustyczna dla miasta Poznania z 2017 r.), które jednak nie muszą być zgodne ze stanem faktycznym w trakcie prowadzenia badań. Należy ponadto uwzględnić założenie, zgodnie z którym warunki akustyczne w mieście mogą zmieniać się w czasie na skutek, m.in. intensyfikacji ruchu lotniczego. Uzyskane wyniki badań, w związku z tym mogą nie być aktualne w kolejnych latach, ze względu na modyfikacje rzeczywistych warunków akustycznych.

Wyniki dla zmiennych związanych z dostępnością do miejskiego transportu publicznego wskazują na niejednoznaczny charakter oddziaływania tego typu infrastruktury na ceny transakcyjne. Zgodnie z wynikami wykonanych analiz dostępność do przystanku tramwajowego w pozytywny sposób wpływa na cenę transakcyjną, wnioskowanie natomiast

nie wykazało istotnych zależności między ceną, a dostępnością do przystanku autobusowego w obrębie analizowanego obszaru.

Wyniki potwierdzają ponadto, że prezentacja analiz rynkowych w postaci prostych kartogramów tematycznych, przedstawiających analizowane zagadnienie w ujęciu przestrzennym, może dostarczyć uczestnikom rynku wielu rzetelnych i niezbędnych informacji pomocnych w podejmowaniu decyzji inwestycyjnych. Informacje te mogą być pomocne nie tylko dla kupujących i sprzedających, ale także dla wyspecjalizowanych grup zawodowych działających na rynku nieruchomości, tj. dla rzeczoznawców majątkowych, pośredników w obrocie nieruchomościami czy zarządców nieruchomości. W związku z tym integracja „prostych" operacji matematycznych oraz narzędzi GIS może przynieść wiele wymiernych korzyści.

Charakter oddziaływania infrastruktury kolejowej na rynek nieruchomości jest niejednoznaczny i może zależeć wprost od przyjętej metodyki opisu tego typu obiektów. Z jednej strony oddziaływanie może być pozytywne w przypadku lokalizacji lokalu mieszkalnego w pobliżu dworca kolejowego, z drugiej jednak strony w sytuacji lokalizacji nieruchomości w pobliżu przebiegu linii kolejowej wpływ ten może być zupełnie inny. Rezultaty wykonanych analiz wskazują na to, że obecność linii kolejowej w bezpośrednim sąsiedztwie nieruchomości lokalowych mieszkalnych negatywnie wpływa na ich ceny transakcyjne. Bezpośrednią przyczyną tego stanu rzeczy może być emisja nadmiernego hałasu komunikacyjnego.

Ze względu na charakterystykę materiału badawczego, który dotyczy danych przestrzennych, analizy tego rodzaju w swojej strukturze powinny uwzględniać autokorelację przestrzenną. Kluczową zaletą modeli regresji przestrzennej (np. GWR) w porównaniu do standardowych modeli regresji (OLS) jest to, że w swojej strukturze uwzględniają one lokalne zależności przestrzenne, co pozwala na uzyskanie wyników charakteryzujących się znacznie większym stopniem szczegółowości na poziomie lokalnym. Prawidłowość tę potwierdzają m.in. uzyskane rezultaty regresji GWR w trakcie IV oraz V etapu badań, zgodnie z którymi współczynniki dla każdego z uwzględnionych atrybutów są zróżnicowane i niejednorodne w obrębie obszaru badań. Przyjęcie jednorodnych wniosków na podstawie regresji OLS dla całego obszaru badań byłoby błędem, który w konsekwencji mógłby prowadzić do podstawowych błędów poznawczych. Dodatkowo wykazano, że analiza GWR umożliwia identyfikację pewnych uniwersalnych zmiennych, których sposób oddziaływania jest porównywalny w skali całego obszaru badawczego.

Zastosowane metody statystyczne umożliwiły zbudowanie modeli cen transakcyjnych nieruchomości lokalowych mieszkalnych na każdym z przeprowadzonych etapów. Należy jednak zaznaczyć, że możliwość wykorzystania tego typu rozwiązań w standardowym procesie wyceny nieruchomości może być ograniczone. Podstawowym problemem jest dokładność poszczególnych modeli, najbardziej precyzyjny wyjaśniał 74% zmienności (etap I). W pozostałych modelach R^2 był wyraźnie niższy, w skrajnych przypadkach miał wartość około 20%. Dokładności tego typu nie są wystarczające do zastosowania modeli w codziennej praktyce rzeczoznawców majątkowych. Sytuacja ta związana jest bezpośrednio z charakterem nieruchomości, które odznaczają się niezależnie od typu indywidualnymi atrybutami. Aspekt ten musi bezwzględnie zostać uwzględniony w procesie wyceny nieruchomości, a zastosowanie tego typu modeli mogłoby te uwarunkowania pomijać.

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36. Rozporządzenie nr 40/07 wojewody wielkopolskiego z dnia 31 grudnia 2007 r. zmieniające rozporządzenie w sprawie utworzenia obszaru ograniczonego użytkowania dla lotniska wojskowego Poznań – Krzesiny w Poznaniu.

3. Streszczenie

Ocena wpływu atrybutów fizycznych, lokalizacyjnych i środowiskowych na ceny nieruchomości lokalowych

W niniejszej rozprawie doktorskiej przedstawione zostały wyniki analiz związanych ze sposobem i wielkością oddziaływania wybranych atrybutów na ceny transakcyjne nieruchomości lokalowych mieszkalnych. Badania zostały przeprowadzone na terenie miasta Poznania zlokalizowanego w zachodniej części Polski oraz w dwóch, wybranych gminach powiatu poznańskiego. Poszczególne analizy zostały wykonane na podstawie danych cen transakcyjnych pochodzących z aktów notarialnych, w przekroju całej pracy zakres czasowy obejmował dane z lat 2014-2022. Badania w szczególności związane były z charakterystyką wybranych atrybutów oraz z ich lokalnymi uwarunkowaniami. Otrzymane w tym kontekście wyniki wskazują na złożoność i niejednoznaczność rynku nieruchomości.

Głównym celem pracy doktorskiej było sprawdzenie, czy wykorzystanie metod statystycznych pozwala na prognozowanie wielkości oraz charakteru oddziaływania wybranych atrybutów na kształtowanie cen nieruchomości oraz zweryfikowanie czy wykorzystanie tych metod może w pewnym stopniu usprawnić proces wyceny nieruchomości. Podstawę wykonanych badań stanowiła analiza statystyczna przeprowadzona z wykorzystaniem wielokrotnej analizy regresji. W pracy wykorzystane zostały następujące metody w celu estymacji hedonicznego modelu cen (HPM): standardowa metoda regresji najmniejszych kwadratów (OLS), regresja ważona metodą najmniejszych kwadratów (WLS) oraz regresja ważona geograficznie (GWR). Atrybuty, które stanowiły podstawę niniejszej pracy związane były m.in. z: dostępnością do terenu prawnie chronionego określonego przez granice Wielkopolskiego Parku Narodowego (WPN), hałasem lotniczym (HL) generowanym przez porty lotnicze Poznań-Ławica i Poznań-Krzesiny, miejskim transportem publicznym (MTP) oraz infrastrukturą kolejową zdefiniowaną przez przebieg linii kolejowej nr 272 Kluczbork – Poznań Główny. Ponadto w analizach uwzględniony został szereg innych cech należących do atrybutów fizycznych, lokalizacyjnych i środowiskowych.

Badanie to stanowi istotny element w dyskusji związanej z charakterystyką mechanizmów zachodzących na płaszczyźnie rynku nieruchomości, a sposób wykonanych analiz polegający na integracji analiz przestrzennych z analizami statystycznymi jest jego niewątpliwą zaletą. Rozwiązanie to z uwagi na swoją przejrzystość może przynieść wiele korzyści m.in. dla przeciętnych uczestników rynku, którzy na podstawie tego typu analiz mogą w dostępny dla siebie sposób zinterpretować skomplikowane mechanizmy rynkowe.

Słowa kluczowe: rynek nieruchomości, ceny lokali mieszkalnych, analiza regresji, lokalizacja

4. Abstract

Assessing the impact of physical, locational and environmental attributes on residential real estate prices

This dissertation presents the results of analyses related to the manner and extent of the impact of selected attributes on the transaction prices of residential real estate. The research was conducted on the territory of the city of Poznań located in the western part of Poland and in two, selected municipalities of the Poznań district. The individual analyses were carried out on the basis of transactional price data from notarial deeds, and in the cross-section of the entire work the data was in the time frame from 2014 to 2022. In particular, the research was related to the characteristics of selected attributes and their local conditions. The obtained results in this context indicate the complexity and ambiguity of the real estate market.

The main objective of the paper was to verify whether the use of statistical methods allows to forecast the magnitude and nature of the impact of selected attributes on real estate price formation, and to verify whether the use of these methods can automate the real estate valuation process to some extent. The basis of the research performed was statistical analysis conducted using multivariate regression analysis. The study used the following methods to estimate the hedonic price model (HPM): standard least squares regression (OLS), weighted least squares regression (WLS) and geographically weighted regression (GWR). Attributes that formed the basis of this study were related to, among others: accessibility to a legally protected area defined by the boundaries of the Wielkopolski National Park (WPN), airplane noise (HL) generated by Poznań-Ławica and Poznań-Krzesiny airports, urban public transport (MTP), and rail infrastructure defined by the course of railroad line No. 272 Kluczbork - Poznań Główny. In addition, a number of other characteristics belonging to physical, locational and environmental attributes were included in the analyses.

This study is an important element in the discussion related to the characterization of mechanisms occurring at the real estate market level, and the method of analysis performed, which consists in integrating spatial analysis with statistical analysis, is its undoubted advantage. This solution, due to its transparency, can bring many benefits, among others, to average market participants who, based on this type of analysis, can interpret complex market mechanisms in an approachable way.

Keywords: real estate market, dwellings prices, regression analysis, location

5. Kopie opublikowanych prac wchodzących w skład cyklu publikacji

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Socio-Economic and Spatial Characteristics of Wielkopolski National Park: Application of the Hedonic Pricing Method

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Abstract: The study aimed to determine the influence of the proximity of Wielkopolski National Park (WNP) on the value of dwelling units in Mosina municipality. The research was conducted based on 1182 residential property transactions in the period from 2014 to 2018. The input data were subjected to spatial and statistical analysis. The main part of the analysis was performed with the use of the hedonic price method (HPM)—WLS (weighted least squares). The use of statistical tools made it possible to find undeniable evidence that the housing prices are positively related to the presence of Wielkopolski National Park, which has also been confirmed by previous research works conducted in other parts of the world.

Keywords: impact of protected areas; housing prices; hedonic regression; national park

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1. Introduction

The market value of a property significantly determines the price it can reach during a market transaction. The value of the real estate is influenced by a number of specific factors, which, depending on the type of property, include physical features such as the size of the plot, the technical condition of the building or the standard of finishing of the building [1]. The factor that has become important over the last few years is a location and its derivative which is an immediate vicinity [2–4].

A choice of a location depends, to a great extent, on the individual preferences of a purchaser. This feature is usually taken into account in the context of accessibility to social infrastructure (e.g., schools), service infrastructure (e.g., grocery stores) or transportation infrastructure (e.g., bus stops) [5–7]. Regarding a location, the factors that determine the state of the immediate surroundings, with a particular emphasis on environmental attributes, are also of great importance [8,9]. In the past years, it has been noticed that the proximity of valuable natural areas, which are favourable to recreation and enable active ways of spending free time, is a feature of undoubtedly high priority according to the hierarchy of "importance" of factors that affect the real estate market [10–13]. The presence of attractive natural areas in the immediate vicinity of a house or an apartment, apart from affecting the prices of the properties, has a direct influence on the demand for a specific type of dwelling unit [14–16].

The areas which are under legal protection not only allow access to nature but also significantly improve the quality of life and perform extremely important environmental functions. The list of benefits of such areas also includes good influence on human health, improvement of the quality of air and preservation of biodiversity [17–19]. Consequently, the above-mentioned advantages of naturally valuable areas have a positive influence on the value of neighbouring properties, which has been confirmed by many research works conducted so far [20–22].

The ground-breaking concepts for determining the impact of selected factors on the value of a real property, based on the hedonic pricing model (HPM), appeared in the 1920s. The first certified and documented study that was performed with the use of the HPM

method was the research conducted by G.A. Hass in 1922, during which the model of agricultural land values was determined [23]. Another key study was conducted in 1967, in which R. G. Ridker, the first in history, used the HPM method to analyse the impact of reduction of air pollution on the prices of dwelling units [24]. In the later years, the theoretical framework of the method was clarified and further specified by such authors as Rosen [25], Lancaster [26] and Maclennan [27]. Furthermore, HPM is one of the methods that can be used to value ecosystem services. Taking this into account, the method may find a wide application in the process of monetary valuation of the environment.

Studies related to the valuation of real estate and to the analyses of the processes that occur in the real property market are very often performed with the use of statistical methods used in mathematics [28–36]. Those methods can be divided into two fundamental groups: basic (traditional) and advanced (modern). Among the group of advanced methods, that constitute the basis of this study, there are such techniques as i.a., artificial neural networks (ANN), hedonic price model (HPM) and techniques related to spatial analyses that have become quite important lately [37]. Two methods that are most often used to identify and assess non-marketable goods are the hedonic price method (HPM) and contingent valuation method (CVM). The main difference between those two methods stems from the fact that in the case of the CVM method the values of non-marketable goods are determined based on questionnaire surveys that show preferences of a properly defined group of respondents [20]. However, taking into account the main objective of this study and the literature on the subject, it can be assumed that the market preferences of a potential purchaser are clearly reflected in the price of the dwelling unit because people, as a rule, opt for properties located near attractive natural areas. Therefore, the HPM method is the most appropriate analytical technique to perform the analysis of the real estate market taking into consideration correct attributes. What is more, the above-mentioned method works very well in this type of analysis, because it takes into account one of the basic characteristics of a property, which is heterogeneity.

Additionally, the HPM method is used in many other types of sciences: natural sciences [38,39], social sciences [40,41] and to analyse other types of markets [42–44]. The HPM method was a basic tool to assess i.a., the impact of selected environmental factors on the value of properties located in several major Polish cities, e.g., in Warszawa [32,45], Kraków [46] or Poznań [47]. The application of the HPM method in this study to assess the impact of legally established protected areas on the value of dwellings units is an extremely important study, despite the many previous examples of the use of this type of method for real estate market analysis. The analysis was performed on the basis of the HPM method described in detail in the literature, therefore this study may serve as a reference for comparable studies evaluating the influence of a selected attribute (proximity of areas under legal protection) on the value of real estate, especially in Poland. The study may not be considered novel or innovative, but it may be important in the process of monetary valuation of the environment.

2. Materials and Methods

2.1. Study Site and Data

The study was conducted in Mosina which is an urban-rural municipality located in western Poland. The northern part of the municipality borders with the agglomeration of Poznań which is an area of fundamental importance for the region and directly determines its development. According to Statistics Poland, the municipality is inhabited by 33,442 persons (according to the data from DEC 2020). The area of Mosina is 172 km^2.

The municipality is located in the immediate vicinity of Wielkopolski National Park which plays an important role in the context of protection of various types of post-glacial landscapes, plant communities and animals. The area of the park is 7584 ha and it is one of the smallest national parks in Poland. Around the park, there is a protective buffer zone and the total area of the park along with the zone is 14,840 ha (Figure 1). The majority of the area of Wielkopolski National Park is covered with forests but, due to intensive human activities,

the landscape is heterogeneous and there are not many large forest complexes there. The flora of the park is dominated by numerous species of plants typical for Central Europe such as sessile oak, common hornbeam and many Euro-Siberian species i.a. mountain-ash or Scots pine. Additionally, due to the diverse soil conditions, there are also such trees as i.a. the English oak and pine. It is worth mentioning that within the WNP there is also a rare attraction because of its magnificent flowers—the golden lily, which in Poland is under strict protection. In addition, other protected species can be observed, such Angelica palustris, Sorbus torminalis or the Drosera rotundifolia. In addition, it is worth noting an important mycobiota for this National Park. A study launched in 2018 [48] identified five species new to Poland—Botryobasidium robustius, Hebeloma subtortum, Leccinum brunneogriseolum, Pachyella violaceonigra and Sistotrema athelioides. The fauna of the Wielkopolski National Park is characterized by an abundance of species belonging to various systematic groups. Protected animals in the park include Lucanus cervus and Cerambyx cerdo, in addition, there are also common species such as Tomicus piniperda or Tomicus minor. Wielkopolski National Park is an area of great importance, especially for the local community. It is a region of nature conservation and it also allows the visitors to enjoy many benefits such as active recreation combined with direct contact with nature [49]. WNP is also characterized by an extremely important social dimension. Previous studies related to WNP [50,51] based on willingness to pay (WTP) have shown that the local community is generally interested in incurring costs for WNP. The assessment of the value of a national park and the size of possible costs depends, of course, on membership in different social groups taking into account such features as age or education, but it is undeniable that WNP is an important element gaining importance in the public consciousness.

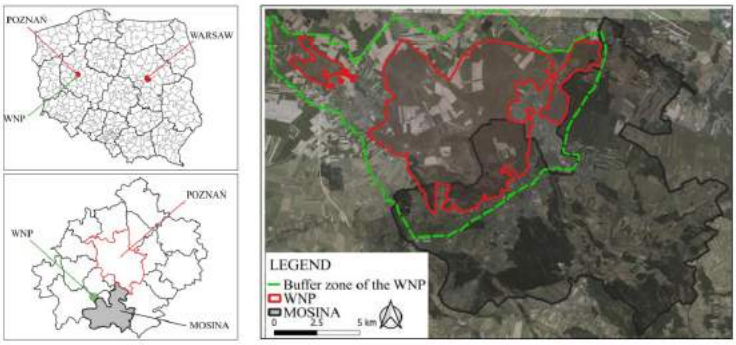


Figure 1. Location of the research facility—Wielkopolski National Park, Mosina municipality.

The research was based primarily on the source data obtained from the District Centre for Geodetic and Cartograph Documentation in Poznań. The data is related to market transactions of residential premises that took place within Mosina municipality in the period from 2014 to 2018—1182 transactions in total (Figure 2). The obtained data was additionally verified, meaning, the transactions that were made in special, non-market conditions were removed from the database, e.g., a sale with a delayed date of a transfer of a property to a purchaser or a bailiff auction, etc. The transaction data obtained from the District Centre for Geodetic and Cartograph Documentation in Poznań is a reliable source of information about the actual and current situation on the real estate market because it is collected directly from the notarial deeds. It makes the data widely applicable in the analysis of the real estate market.

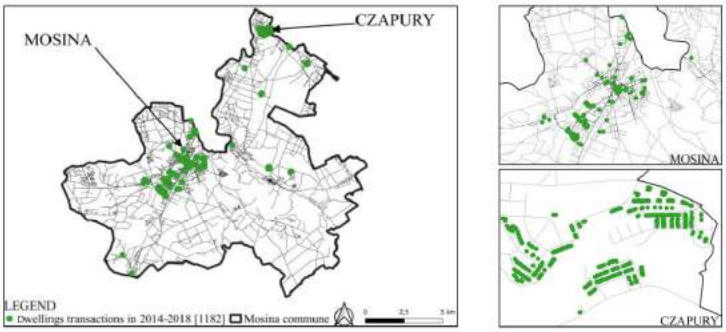


Figure 2. Location of the assessed properties.

The basic data stored in the database of this study (for each transaction) includes information related to: transaction date, transaction price, surface area (of a dwelling unit), surface area of additional premises (e.g., a storage room or a basement) and details regarding the floor the unit is located on. The main downside of this type of data is the lack of its completeness in terms of detailed characteristics of the main factors that affect the value of a property such as immediate surroundings or a technical condition of a building. An attempt to identify and indicate factors that significantly affect the value of residential premises based only on the data collected in this register cannot be considered, by definition, an acceptable approach. The primary reason for the above is the unique nature of each property and the fact that the value of the premises is also affected by several other factors which are not defined in the registry under review. To eliminate the above-mentioned issue related to the lack of completeness of the data, additional information was obtained about the analysed housing properties such as i.a.: details regarding the immediate neighbourhood and exact location.

2.2. Methods

The HPM method is a tool that is used to examine the correlation between a price of a property (e.g., an apartment) and its most important characteristics. The market participants usually purchase residential premises assuming that it is a good way of capital protection. The investment decisions are based on a detailed description of the property and its usefulness. In the case of a dwelling unit, the main factors that determine its investment attractiveness include surface area, number of rooms, age and technical condition of the building, availability of other amenities such as a parking space or a lift [22,37]. Additionally, an extremely important factor is location, which is usually considered in terms of accessibility to such facilities as schools, shopping centres and recreational areas [13,32]. What is more, there are other social and environmental factors related to location and immediate surroundings that directly affect the price that potential investors are willing to pay for a property [2,9].

The most important objective of the model designed with the use of the HPM method is to answer the question of how the selected, analysed factors affect a value of a property. The main idea of the HPM models is the assumption according to which the price of a property is defined by several selected attributes. Consequently, the obtained model makes it possible to determine the value of analysed features that constitute individual components of the final price. The attributes of real estate adopted for the analysis, such as location or access to legally established protected areas, constitute explanatory variables [20,21,37]. Hence, the price of a dwelling unit can be illustrated by a standard regression equation.

$$P = \beta_0 + \sum_{i=1}^{K} \beta_1 X_i + u, \quad (1)$$

where P is the price of a dwelling, β is the regression coefficient, X_i is an attribute of a dwelling, u is a random error.

To perform analyses of the real estate market employing the HPM method, a regression function based on the natural logarithm is usually used. This type of solution is very popular as there is a possibility to change the value of a selected attribute in proportion to the changes in other features. The linear models, that belong to a different group of tools, only allow assessing the level of influence of improvement or deterioration of a given attribute, e.g., technical state of all buildings in the analysed group of residential properties. The linear models do not allow to identify the impact of improvement or deterioration of the quality of a selected attribute for dwelling units of, for example, different surface areas. Additionally, the advantage of models based on a logarithmic function is also the easy way of interpretation of individual coefficients and elimination of the issue of variability of a random component [52]. Taking into account the above, this study is based on a logarithmic model.

In this research, one of the basic variants of hedonic regression was used: WLS (weighted least squares). The assessment with the use of the weighted least squares method was performed as follows: performance of OLS regression (ordinary least squares), performance of auxiliary regression where the dependent variables were the squares of the residuals, the input independent variables plus their squares. The values obtained from hedonic regression were used to create a series of weights, then the original model was assessed using the weighted least squares method [37].

The most important issue when analysing the real estate market is to select the right factors that most significantly affect the price of a property. A basic characteristic feature of residential premises is heterogeneity and, as a result, some features that are relevant for the price of a particular type of real property may be of marginal importance for another sort of real estate. In the case of residential units, significant characteristic features can be divided into three categories of variables that define: dwelling unit, neighbourhood and environment [20]. What is more, an additional category of variables can be created that would define social, economic and planning conditions within the local real estate market. Each group of variables includes many attributes depending on the type of premises and economic, social or local conditions (Table 1).

Table 1. Categories of variables created based on the literature on the subject.

Category	Variable	Author
Characteristics of a dwelling unit	Surface area	Trojanek et al. [37]
	Number of rooms	Escobedo et al. [22]
	Type of dwelling unit	Park et al. [20]
	Age of a building	Sander and Haight [53]
	Parking space/garage	Ko et al. [54]
	Upper-floor location	Oh and Lee [55]
	Type of building construction	Trojanek et al. [37]
	Form of ownership	Marano and Tajani [56]
	Accessibility to basement	Trojanek et al. [37]
	Energy efficiency	Zancanella et al. [57]
Characteristics of neighbourhood	Distance to a town centre	Payton et al. [58]
	Distance to schools	Hwang et al. [59]
	Access to public transportation	Kim and Kim [60]
	Distance to shops	Oh and Lee [55]
	Distance to recreational areas	Tyrväinen [61]
	Bothersome neighbourhood (airport, etc.)	Kopsch [62]
	Distance to lakes	Sander and Haight [53]
Characteristics of environment	Distance to green areas, parks	Liebelt et al. [63]
	Distance to legally protected areas	Pearson et al. [64]
	Distance to other valuable natural areas (rivers, mountains, etc.)	Ko et al. [54]

Table 1. *Cont.*

Category	Variable	Author
Characteristics of local social, economic and planning conditions	Air pollution	Chen and Chen [65]
	Amount of tax	Sander and Haight [53]
	Demographic structure	Adegoke et al. [66]
	Employment opportunities	Payton et al. [58]
	Prospects of economic development	Perdomo [67]
	Average net income	Roebeling et al. [68]
	Occurrence of planning barriers	Hussain et al. [69]

According to the characteristics of the research subject, the literature review and the basic assumption of the conducted analysis, the most important characteristic features in the first group include surface area, type of building construction, floor the unit is located on, accessibility to basement and height of a building. Variables from the other groups such as access to public transportation, schools and legally protected areas are also extremely important and when using the HPM method those are the primary factors that affect the price of dwelling units. Ultimately, some important features related to characteristics of a residential unit such as type of building construction or age of a building were not taken into account in the analysis. The last two features were not analysed because the vast majority of transactions in Mosina municipality concerned premises related to development investments which were performed at the same time and to units constructed with the application of the same technique.

Considering the above-mentioned assumptions, the hedonic function of the price may be presented in the following manner:

$$\ln(P) = f(\text{structural characteristics, location, transaction time, accessibility to WNP}) \quad (2)$$

Taking into account the selected variables, the next stage of the study was performed and it involved defining variables for the analysed properties. The variables were determined according to the adopted criteria. The actual distance to the selected attributes was measured with the use of QGiS 3.16.1 software.

2.3. Variables

2.3.1. Transaction Year

When it comes to real estate, the date of the transaction is extremely important. Due to its unique nature, the real property market is influenced by, i.a., social, political, demographic and economic conditions that change over time. The analysis covered the years 2014–2018. The greatest number of transactions related to residential premises was recorded in 2017 (330) while the lowest number was recorded in 2016 (192).

2.3.2. Surface Area of the Dwelling Unit

The actual surface area of the properties in the analysed set of residential premises was varied and it ranged from 26.12 m^2 to 162 m^2. Whereas, the average size of the surface area was 64.16 m^2. The data was obtained from the database of the District Centre for Geodetic and Cartograph Documentation. The surface area is of key importance when it comes to the price of a property and it is usually assumed that the unit price of premises with a smaller surface area is greater compared to the unit price of similar premises but of a much larger surface area. This rule is not always the case and may depend on local conditions.

2.3.3. Floor

The floor that the dwelling unit is located on is an extremely important variable from the point of view of accessibility to the apartment and security. This attribute should be assessed taking into consideration the height of the building the premises are located in. It is assumed that the dwelling units located on the first and middle floors are usually

more expensive. On the other hand, in taller buildings, where there is a lift, greater prices are achieved by apartments located on higher floors. The floor that the unit was located on, in the case of the assessed properties, was determined based on the author's own analyses. In the analyzed group of transactions, the vast majority of dwellings were located on the ground or top floor (836), the remaining transacted dwellings were located on the intermediate floors (346).

2.3.4. Height of the Building

This is the feature that is directly related to the characteristics of the building in which the apartment is located and the floor that the dwelling unit is situated on. When comparing similar dwelling units located on the same floor in two different buildings, the height of a building can make a significant difference when it comes to price. Regarding the assessed set of transactional data, it was noticed that the heights of the buildings were different which was why this attribute was included in the analysis. In the analyzed transaction group, a comparable number of real estate transactions were identified in lower buildings (up to two floors)—629 transactions and in higher buildings (above two floors)—553 transactions.

2.3.5. Access to Public Transport

This feature was considered in terms of accessibility to bus stops; tram stops, for example, were omitted due to their lack in the analysed area. Public transport plays a significant role in Mosina municipality as it enables convenient access to Poznań what is especially important for those working in the capital of Wielkopolskie Voivodship. Within Mosina municipality, there are mainly stops for city buses and they are located at roadsides. The distance between a dwelling unit and the nearest bus stop was measured regardless of the type of stop. The specified value corresponds to the actual distance that a person has to cover to get from the residential unit to the bus stop, taking into account local pedestrian routes. For the analyzed transactions, the average distance to the nearest bus stop was 0.5 km, the minimum distance for one dwelling unit was 0.03 km, and the maximum distance was 2.21 km.

2.3.6. Distance to Schools

This is another important feature that is often taken into account by the real estate market participants. Access to school infrastructure in the form of primary schools and nursery schools was analysed. Other types of schools were excluded from the analysis because they are not of key importance when it comes to selecting a residential property. Older students, e.g., attending a high school that is located further away, can easily get to school using public transport. In the case of younger schoolchildren, the possibilities of using public transport are usually limited and potential commuting must be planned with all the appropriate precautions. From the point of view of this research, this is clearly an important issue, especially for young families. Usually, students choose a school that is located closest to their place of residence; therefore, in the study, the distance to the nearest school was measured taking into account the existing road network. The average distance for all dwellings to the nearest school infrastructure was 1.88 km, the minimum distance for one dwelling was 0.06 km and the maximum distance was 6.69 km.

2.3.7. Distance to the WNP

Wielkopolski National Park is a special area for the inhabitants of the region. It enables active recreation and direct contact with nature. A lifestyle based on, i.a., relaxation in areas that are not significantly transformed by a man has been gaining importance over the recent years. According to the conducted literature review, one of the effects of the proximity of valuable natural areas is the increase in the price of residential premises that are located in its immediate vicinity. In the study, the actual distance between the residential units and the nearest entrance to the park was measured. Based on the measured distances, we

identified that the average distance for this feature was 1.13 km, the maximum was 6.46 km, while for the minimum distance, several dwellings were located in close proximity to the entrance to the WNP.

2.3.8. Distance to the Centre of Mosina

This feature is one of the derivatives of location. Generally, properties located within a walking distance to the town centre are of higher prices compared to the residential units that are situated in the suburbs or on the outskirts of the municipality. As in the case of other attributes, the actual distance between the dwelling units and the centre of Mosina was determined. The mean value of the measured feature was 5.41 km. In the analyzed set, there were several dwellings located directly in the city center and for them, the minimum value of the attribute was recorded, while the dwelling located farthest from the city center was at a distance of 10.06 km.

2.3.9. Distance to Poznań

This is another attribute that is related to location. In the case of the analysed local real estate market, the distance to a large urban agglomeration is an important factor that should be considered when defining the processes occurring within the market. Poznań plays an important role in the development of the surrounding areas, the city guarantees many attractive workplaces and directly contributes to the increase in the quality of life. Within the local real property market, a certain trend has been observed, namely, the residents of Poznań prefer to move outside the city to the neighbouring areas. At the same time, those areas should be situated as close as possible to the city to guarantee easy and quick access to Poznań. For each property, the actual distance to the administrative borders of Poznań was determined. In the analyzed transaction group, the average distance to the administrative borders of Poznań was 6.80 km. For one of the analysed dwellings located in the southern part of the municipality, the distance was 17.81 km and this was the maximum value of the attribute.

The way the analyses were conducted can be divided into four basic stages. The first stage of the research was to select an appropriate method of valuation of the analysed features. Based on the literature review and the author's own study, the HPM model was selected as the most appropriate one for this type of research. The second stage was to select relevant variables that, based on the literature review and the characteristics of the local real estate market, were appropriate while taking into account the prices of the properties and were consistent with the main objective of this study. The third stage involved defining the selected variables for the analysed properties. The last, fourth stage, was to assess the appropriate parameters of the function with the use of SPSS Statistics software. The property price included in the model was the dependent variable and the analysed attributes were explanatory variables.

3. Results

The performed analyses were divided into two groups. The first part of the research consisted of the initial verification of the influence of accessibility to Wielkopolski National Park on housing prices and it was performed based on spatial analysis. The second part of the research, the most important one, was conducted based on statistical analyses—the hedonic pricing model.

3.1. Spatial Analysis

To initially assess the influence of accessibility to Wielkopolski National Park on the transaction prices of residential units in Mosina municipality, a spatial analysis was conducted with the use of QGiS software. The spatial analysis was divided into two stages. In the first stage, the collected transactions were divided into two groups: the treatment group and the control group. The treatment group included the units located in the immediate vicinity of Wielkopolski National Park (up to approximately 1 km—

395 transactions) while in the second group, there were other properties situated more than 1 km away from the borders of the park—787 transactions (Figure 3).

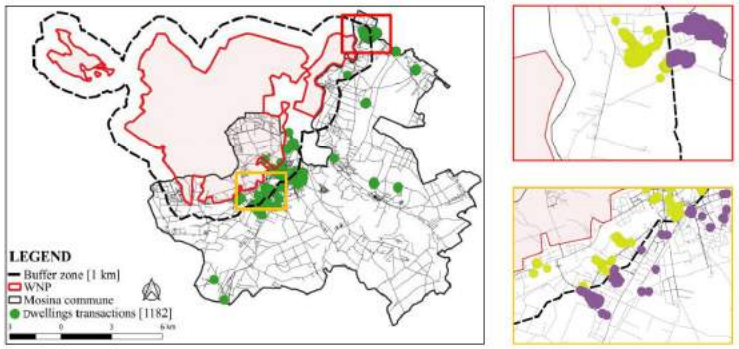


Figure 3. Spatial analysis—up to 1 km away.

Basic descriptive statistics for the explanatory variables and the dependent variable (mean and standard deviation) were compiled for each group. The average price of the units located within the distance to the park of up to 1 km is higher than the price of the premises situated outside the zone (Table 2).

Table 2. Descriptive statistics of residential dwelling transactions

	Treatment Group		Control Group	
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**
Price (PLN/m^2)	3731.41	628.58	3317.08	558.18
y2018	0.13	0.34	0.18	0.39
y2017	0.30	0.46	0.27	0.44
y2016	0.11	0.32	0.19	0.39
y2015	0.21	0.41	0.14	0.35
y2014	0.25	0.43	0.22	0.41
Surface area (m^2)	65.47	19.04	63.51	13.63
DCC (Distance to the centre of Mosina)-km	5.33	4.19	5.45	3.61
DWNP (Distance to WNP)-km	0.62	0.21	1.38	0.76
DP (Distance to Poznań)-km	5.70	5.15	7.35	5.83
DT (Distance to a bus stop)-km	0.34	0.17	0.58	0.30
DS (Distance to schools)-km	2.21	1.65	1.72	1.51
F1 (ground and the top floor)	0.84	0.37	0.67	0.47
F2 (other floors)	0.16	0.37	0.33	0.47
H1 (a building up to 2 floors)	0.72	0.45	0.44	0.50
H2 (a building of more than 2 floors)	0.28	0.45	0.56	0.50
Number of observations	395		787	

The second stage of spatial analysis was conducted by dividing the analysed transactions into 6 groups. The classification was performed based on the distance to the borders of Wielkopolski National Park. The following classification criteria were adopted: <0.50 km, 0.50–0.75 km, 0.75–1.00 km, 1.00–1.25 km, 1.25–1.50 km, >1.50 km (Figure 4).

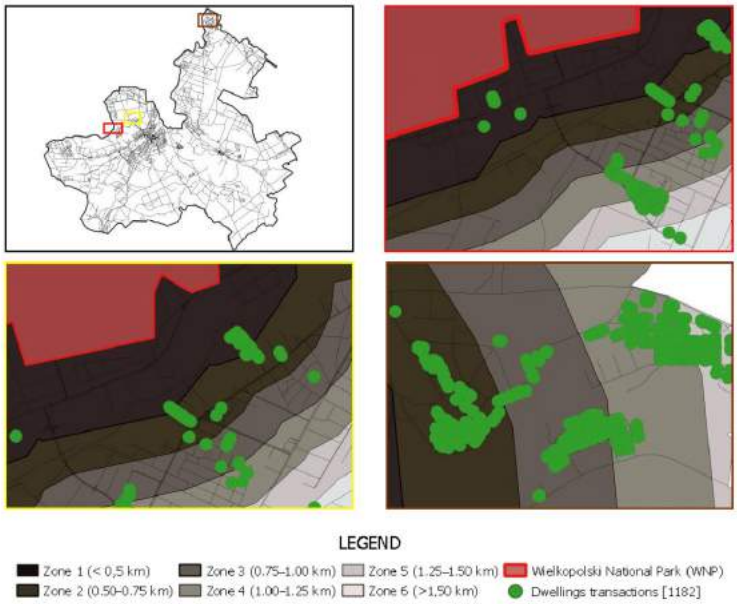


Figure 4. Classification of transactions based on the distance to Wielkopolski National Park.

The main purpose of dividing the research material into 6 groups was to refine previous analyses and to present the changes in prices within each group. The most important descriptive statistics from the point of view of the analysis were compiled for each group—the mean and the median of prices (Table 3).

Table 3. Mean and median of prices for the analysed groups.

	Median of Prices (PLN/m^2)	Mean/Average Price (PLN/m^2)	Number of Observations
<0.50 km	3906.02	3660.18	110
0.50–0.75 km	3905.86	3750.73	166
0.75–1.00 km	3493.43	3512.48	192
1.00–1.25 km	3319.91	3390.68	392
1.25–1.50 km	3341.08	3319.98	249
>1.50 km	3267.23	2949.79	73

The average prices of residential premises in the analysed groups, determined based on the distance criterion, changed significantly in the assessed set of transaction data (Figure 5).

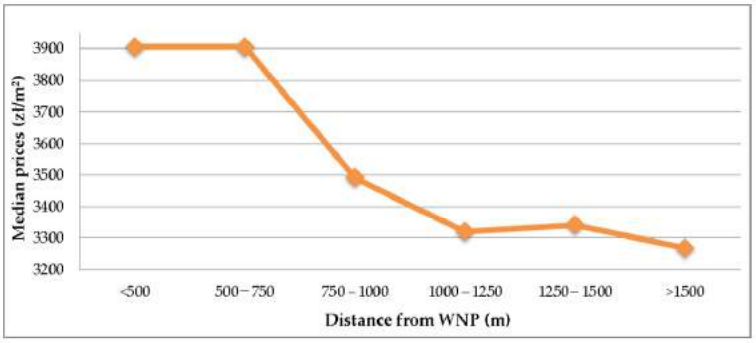


Figure 5. The median of transaction prices in designated groups.

Spatial analysis allows observation of the initial correlation between the transaction price and the accessibility to Wielkopolski National Park. However, the analysis cannot be used to draw statistically significant conclusions regarding the impact of accessibility of Wielkopolski National Park on the prices because, in the analysis, other most important characteristics are not taken into account, namely, the ones that significantly determine the price of a dwelling unit within the local real estate market.

3.2. *Statistical Analysis*

The characteristic features of the residential units analysed in the study included attributes related to the dwelling unit (surface area, floor, height of the building), the location (access to public transport, access to schools, access to legally protected areas, distance to the centre of Mosina, distance to Poznań). Additionally, in the model, a feature related to the year in which the transaction was finalised was taken into consideration. The defined variables were chosen based on the availability of the data and the characteristics of the local real estate market. The adopted qualitative and quantitative variables were, first of all, defined in a way that allowed their use in the model (Table 4).

Table 4. Qualitative and quantitative variables used in the model.

Feature	Symbol	Characteristics of the Feature
Price	Price	Price of the residential unit (PLN/m^2)
Year	y2018 y2017 y2016 y2015 y2014	5 variables used in the model. If the residential unit was sold in a given year, they are assigned the value 1, otherwise, they are assigned the value 0.
Surface area	Surface area	Surface area of the residential unit in m^2
DCC	DCC	Distance to the centre of Mosina (km)
DWNP	DWNP	Distance to Wielkopolski National Park (km)
DP	DP	Distance to Poznań (km)
DT	DT	Distance to a bus stop (km)
DS	DS	Distance to schools (km)
Floor	F1 (ground floor and the top floor) F2 (other floors)	2 variables used in the model. If the residential unit is located on a specific floor it is assigned the value 1, otherwise, it is assigned the value 0.
Height	W1(a building up to 2 floors) W2 (a building of more than 2 floors)	2 variables used in the model. If the building has a certain height it is assigned the value 1, otherwise, it is assigned the value 0.

In the next stage, relevant function parameters were assessed with the use of SPSS Statistics software. The natural logarithm of housing prices in the model was the dependent variable while the analysed attributes were the explanatory variables.

With the use of the weighted least squares method, it was possible to explain approximately 74% of the price fluctuations. Most of the variables used in the model turned out to be statistically significant. The predicted values of individual coefficients were correct. With the conducted analyses, based on the collected data, it was not possible to identify three coefficients for the variables y2017, F2 and H1 due to the lack of variation of the variable.

It was observed that, over the studied years (2014–2018), the date when the transaction was made had a significant impact on the transaction prices of residential premises. The global crisis that occurred in the period from 2007 to 2009, also affected the prices of dwelling units in Poland and their value was significantly lower over the years following the crisis [70]. However, referring to the latest reports of the National Bank of Poland related to housing prices, it can be noticed that after the downward trend which occurred in the above-mentioned period, the market has clearly recovered. The prices of dwelling units in the majority of Polish cities continue to rise, which is also the case for the analysed area.

Based on the statistical analysis performed for this study, it can be observed that the location-related features have a significant impact on the transaction prices of residential premises. The larger the distance to Poznań the lower the transaction prices. On the other hand, the dwelling units that are located in the centre of Mosina are cheaper than those located in other parts of the municipality. The obtained results confirm some preferences of the market participants such as living in a quieter area and, at the same time, in the regions that are well connected to a large urban centre. This was also observed in a study conducted within Wielkopolskie Voivodship [71].

Taking into account the major objective of this study, the statistical correlation between housing prices and the accessibility to Wielkopolski National Park is most significant. The use of a hedonic regression function based on a natural logarithm made it possible to determine the coefficient of change in the price of a dwelling unit concerning the change in the distance of the residential premises to the entrance to Wielkopolski National Park. The coefficient for the feature (DWNP) was assigned a value—0.126 (Table 5) which means that a unit located at a greater distance (1 km) from the entrance to the park achieved a lower price in the market by approximately 12.6% than a similar unit located in closer proximity. The application of the WLS model confirmed the conclusions obtained based on the preliminary spatial analysis.

Table 5. WLS estimation results (the dependent variable—the natural logarithm of the price of 1 m^2).

	Coefficient	Standard Error	T-Value	*p*-Value
Constant	8.490	0.045	189.693	0.000
y2018	0.030	0.014	2.133	0.033
y2016	0.017	0.014	1.172	0.241
y2015	0.033	0.013	2.600	0.009
y2014	0.054	0.015	3.656	0.000
Area	−0.003	0.000	−13.995	0.000
DCC	0.001	0.008	0.056	0.096
DWNP	−0.126	0.013	−9.662	0.000
DP	−0.011	0.003	−3.702	0.000
DT	0.181	0.034	5.364	0.000
DS	0.001	0.014	0.079	0.937
F1	−0.020	0.013	−1.556	0.120
H2	−0.050	0.019	−2.646	0.008
R^2		0.739		
N		1182		

4. Discussion of the Results

This study is one of the first assessments of the influence of accessibility to legally protected areas on the prices of residential properties. There are only a few studies that have been conducted so far that are related to the analysis of the impact of the proximity of a national park on the value of a real estate and they mainly concern such countries as Australia [64], the United States [72] and the United Kingdom [73]. Most often, the research works for which the HPM method has been used were various types of analyses of the impact of accessibility to urban green areas [20,22,32] or airports [37,52,62] on the prices of dwelling units. Moreover, the selection of factors that are adopted for this kind of analysis is often determined by local conditions and adequate knowledge of the local market. However, a direct comparison of the results obtained in this research with the existing studies may be difficult due to one of the most significant characteristic features of the real estate market—heterogeneity which may result from i.a., different locations or different types of residential properties.

It should be noted that the conducted analyses were based on a wide range of data on the transactions concerning the size of the research object. The analysed set of transactions included a total of 1182 residential units. Similar types of studies conducted in Poland, in the previous years, were based on a comparable number of transactions, or a larger number, however, those studies concerned much larger administrative units such as Poznań or Warszawa [37,45,52].

This research assessed how and to what extent the prices of residential premises change with regard to one of the most important features of the local real estate market—accessibility to Wielkopolski National Park. In the study, this feature was defined by the actual distance between the dwelling unit and the entrance to the park, taking into account the local road infrastructure. The Euclidean distance was not taken into account in this statistical analysis. The use of the network distance in the model has many benefits, however, most importantly, it gives the possibility of a reliable mapping of the processes occurring within the local market [12,20].

The use of a logarithmic model allowed us to identify the percentage change in the transaction price of a dwelling unit in relation to the change in the distance of the premises to the entrance to Wielkopolski National Park. Within the local real estate market, accessibility to Wielkopolski National Park proved to be a statistically significant attribute affecting the prices of real property. At the same time, it is important to note that real estate is a particularly important good. The price of real property may depend on several features that are typical for the local nature of the real estate market. Any kind of analyses of the real estate market should be conducted comprehensively. Additionally, the method of the impact of selected attributes may vary depending on the type and spatial extent of the property market. When conducting analyses of the real property market, it is important to be aware that the impact of significant factors on prices may change over time and it also depends on the changes in local planning, social, economic and political conditions [74–76]. The analysis carried out allowed us to categorize the variables and indicators adopted for the analysis into one of two groups in relation to price: enablers-constraints or barriers-drivers (Table 6).

Table 6. Categorisation of variables by nature and magnitude of impact on price.

Nature and Manner of Influencing the Price of a Dwelling	
Advantageous attributes	Disadvantageous attributes
++ (high)	−− (high)
Less distance to Wielkopolski National Park	Less distance to a bus stop
	Building of more than 2 floors
+ (low)	− (low)
Transaction year	Less distance to schools
Less distance to Poznań	Ground floor and the top floor
Smaller surface area of the residential unit	Less distance to the centre of Mosina

According to this study, there is a statistically significant correlation between prices of residential premises and accessibility to Wielkopolski National Park. However, even though the obtained results are properly justified, there are some certain limitations to the solution mainly resulting from the lack of data. In the context of residential units, one of the most important features seems to be the standard of finishing (interior of the unit). However, in this study, there was no technical possibility to include this variable in the model due to the lack of information on this attribute in the available sources of data. Taking this variable into account when constructing the WLS model would certainly contribute to increasing its accuracy and it would be possible to describe, in a more precise way, the actual processes and mechanisms occurring within the local market. Moreover, the restrictions of the presented method may be related to the fact that the impact of proximity to legally protected areas in other cities/regions of Poland may be different as it depends on regional conditions. Finally, it is worth noting that the Mosina commune occupies an area of 172 km^2, which makes the study area isn't very large. Consequently, it is difficult to draw universal conclusions that could be formulated for larger study sites.

In connection to the above, this type of research should be conducted in other cities/regions of the country for legally protected areas, to have the possibility to compare the conclusions to the results obtained in this study. To increase the possibility of comparing the studies, future analyses should be based on similar assumptions related to the selection of real property, variables and applied methodology. Application of this type of approach in future research may guarantee determination of the regional impact of the analysed feature on prices of residential units.

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The Influence of Aircraft Noise on the Prices of Residential Properties on the Example of Poznań

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Abstract: The article analyses the influence of aircraft noise on the transaction prices of residential premises within the Poznań property market. The paper analyses the set of properties, subject to the transaction from the first to the fourth quarter of 2020. In total, 1550 properties were examined. The study defined basic attributes of all premises, exhibiting the most significant influence on their price. The research conducted using the hedonic regression allowed for the identification of crucial evidence that aircraft noise negatively affects the property transaction prices.

Keywords: aircraft noise, property prices, hedonic methods

1. Introduction

Noise generated by aviation, as well as any additional, ancillary activities, constitutes an important issue, particularly for market participants, potentially interested in purchasing premises in the vicinity of the airport (Bishop & Laing 2020). It should be noted that, over the past years, as a result of substantial, technological progress, the noise from a single aircraft has been significantly reduced (Zellmann et al. 2019). Activities aimed at reducing noise emissions occur, among others, in connection with the implementation of the principles of sustainable development, which nowadays rise in importance (Dube & Nhamo 2020). However, it should be emphasised that, over the last years, along with the reduction of noise emitted from a single aircraft to the environment, air transport has been gaining in importance (Zhang & Graham 2020). As a consequence, despite the technological progress, the absolute value of noise emitted

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to the environment from aviation activities has not decreased. In places particularly exposed to noise, it is extremely important to conduct activities involving the local spatial structure, aimed at reducing the negative impact of noise, generated by the transport industry (Podawca & Staniszewski 2019).

Air transport is considered to be the safest means of travelling, fulfilling the fundamental demands of sustainable transport and enabling fast and accessible for everyone movement between distant countries and continents (Bobrova & Stepanov 2019). Regardless of the presented, indisputable advantages of this form of transport, it also generates many crucial, economic and social costs. The most significant costs of such transport are borne by the residents of properties, located in the vicinity of large, international airports, as well as smaller, local ones. An increased number of flights, combined with their duration, directly affect the amount of noise emitted, which, in turn, results in a significant deterioration in the living conditions of the owners of properties adjacent to the airport (Eves & Blake 2016). It is important to examine the consequences of the airport's proximity on people residing in the area of its impact.

This paper aims to examine the impact of aircraft noise on the value of properties. The property market is unique, while the premises are considered to be specific goods, characterised by several individual features, including economic, legal, environmental and institutional ones. The property value, depending on its type, is influenced by its direct features (technical condition of the building, the parcel's size, finishing standard, etc.) and attributes considering the condition of the property's immediate surroundings, i.e. the quality of recreational areas, air pollution, vicinity of troublesome industrial facilities, etc. (Radzewicz & Wiśniewski 2012). The proximity of airports is also placed among the most important, indirect factors (Batóg et al. 2019). Complete analyses determining the impact of significant factors on the property value should involve factors from both the first and the second group.

2. Literature review

The activity of airports generates a number of social and economic consequences. Noise emitted from the airport's operation constitutes one of the most significant social costs, which directly affects residents of the impact zone. One of the available methods for examining the magnitude of the said costs consists in the analysis of changes in the value of properties located in the vicinity of the airport. Most frequently, such an impact is determined based on the preferences of the property market's participants, including transactional data concerning previous sales. The analyses usually apply models of hedonic price or multiple regression (Trojanek et al. 2017, Winke 2017, Thanos et al. 2012).

To analyse the impact of excessive exposure to noise on the property, the study employed the NDI (Noise Depreciation Index), defined as

a depreciation/amortisation index or the NSDI (Noise Sensitivity Depreciation Index), understood as an index of sensitivity to the decreasing values. The basic objective of both these indicators is to determine how the price of the property is affected by a 1dB change in the noise level. The subject literature, assessing the impact of noise on the value of properties has been previously analysed (Nelson 2004, Schipper et al. 1998, Bateman et al. 2001, Wadud 2013, Trojanek et al. 2017, Kopsch 2016) (Table 1).

Table 1. A summary of literature reviews conducted in relation to the NDI

Author/ authors	NDI	Study period	Area of the study	Scope of the study
Nelson	0.28-1.49%	1969-1993	USA, Canada	23 airports
Schipper et al.	0.1-3.57%	1967-1996	USA, Canada, Australia, UK	19 airports
Bateman et al.	0.29-2.3%	1960-1996	USA, UK, Canada, Australia	30 reviews
Wadud	0-2.3%	1970-2007	USA, Canada, Australia, UK, Netherlands, France, Switzerland, Norway	65 reviews
Trojanek et al.	-0.8-2.12%	1995-2014	China, Switzerland, Netherlands, Germany, Greece, Poland, Thailand, France	14 reviews
Kopsch	0.13-2.3%	1960-2009	Australia, UK, USA, Germany, Thailand, Netherlands, Canada, Switzerland	44 reviews

The presented NDI values reach different levels for various countries and individual airport examples. Therefore, it can be concluded that the prices of premises react differently to the proximity of the airport, which may be directly related to one of the main characteristics of the property market – its local character. The size and manner of impact may be furthermore associated with the scale of the airport, the spatial structure of existing buildings, different forms of noise measurement and the economic development of the country (Wadud 2013).

Analysing some of the recent studies regarding the impact of noise on the prices of properties located in the vicinity of airports, it can be noticed, that the majority confirms the negative influence of airport proximity on the said values (Chalermpong & Klaiklueng 2012, Püschel & Evangelinos 2012, Nguy et al. 2014). The exceptions are two studies (Huderek-Glapska & Trojanek 2013, Trojanek 2014) including the case of the Warsaw airport, in which, contrary to other studies, apartments and houses located closer to the airport were evaluated higher. Within the analysed studies, the obtained NDI values reached between -0.8 and 2.12% per 1 dB. It should be noted that a direct comparison of indicators received for the purposes of those studies may be misplaced, due to disparities in the type of the analysed properties, different methods of noise measurement, as well as various sources of data.

3. Area and material of the study

3.1. Area of the study

Poznań, located in the central-western part of Poland, constitutes the central part, as well as the capital of the Wielkopolskie Voivodship. According to the Statistics Poland, the city is inhabited by 533,830 residents (as of August 2020). The city area amounts to 261.9 km^2.

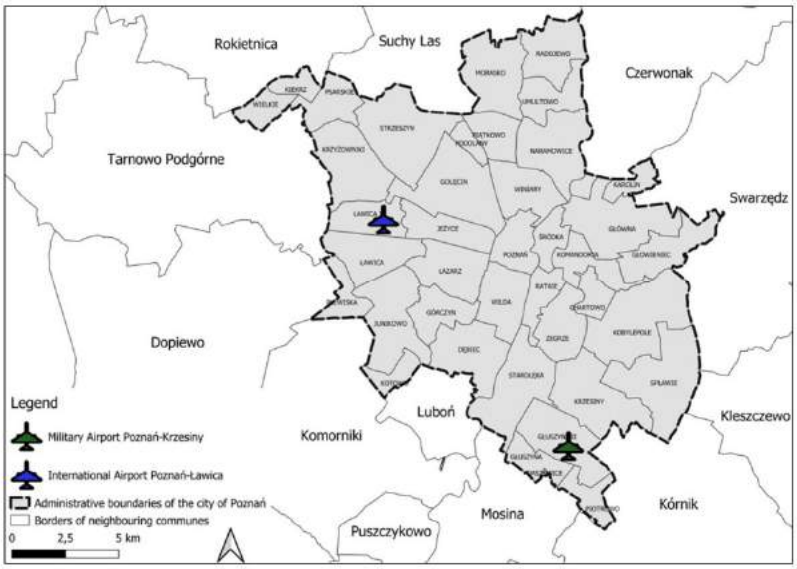


Fig. 1. The location of airports in Poznań. Source: own study

There are two airports in Poznań: Poznań–Ławica Henryk Wieniawski Airport (in the western part of the city) and the 31st Air Base, known as the Poznań-Krzesiny Airport (in the southern part of the city), owned by the National Air Force Command (Fig. 1).

Poznań-Ławica Henryk Wieniawski Airport was opened in 1945. The total area of the airport amounts to 310 ha, while its capacity reaches 3 million (the airport is capable of providing service to 3 million passengers each year). In 2019, the airport held a total of 31,923 air operations (Fig. 2A), within which, 2,379,635 passengers took advantage of flights (Fig. 2B).

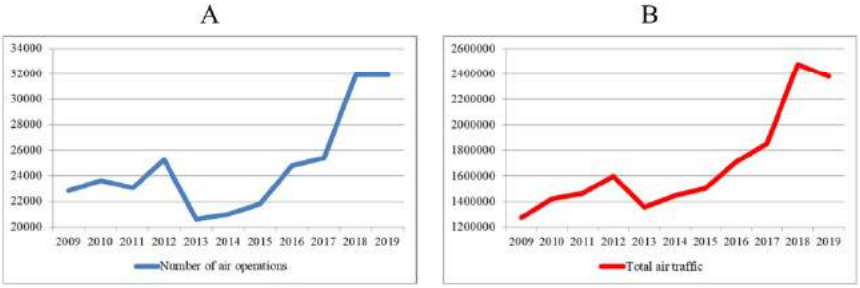


Fig. 2. The number of air operations at Poznań-Ławica Airport in 2009-2019 (A), total air traffic at Poznań-Ławica Airport in 2009-2019 (B)

Poznań-Krzesiny Airport is located within the are of the Military Unit No. 1156. The 31st Tactical Air Base is located in the same area, approximately 8 km from the city centre. Data obtained from the Environmental Noise Protection Programme for the City of Poznan in 2018 indicate that, in 2016, the total number of air operations occurring at the military airport increased by 12.5%, compared to 2011.

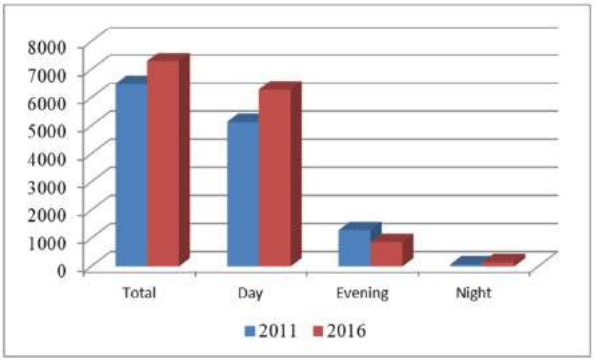


Fig. 3. The number of air operations at Poznań-Krzesiny Airport in 2011 and 2016

3.2. Study material

The following study is based on two groups of source data. The first, basic group, consists of data obtained from the Board of Geodesy and Town Cadastre "GEOPOZ" in Poznań, on the residential property transactions concluded in the city in 2020. The framework of this study does not involve property transactions, concluded in particular conditions, i.e. in non-market conditions, such as sale with a delayed date of release of the property to the buyer, or in the event of a bailiff's auction.

Transactional data obtained from the Board of Geodesy and Town Cadastre in Poznań were based on notarial deeds. The basic information collected in this database includes data on the transaction date and price, surface area (of the apartment), area of auxiliary premises, as well as information regarding the floor on which the dwelling is located. An attempt to determine factors that significantly affect the value of a property on the sole basis of data from such a register cannot be considered an acceptable approach, due to the unique nature of the property, according to which, its value is influenced by several attributes, undefined in the said register. To eliminate the problem related to the absence of complementarity data, additional information about the analysed properties, including the nearest neighbourhood and detailed location, was obtained.

The second group of source data consists of the information derived from the noise map of Poznań from 2017, related to aircraft noise occurring within the areas of restricted use of the Poznań-Ławica Airport and the Poznań-Krzesiny Airport.

The restricted use area of the Poznań-Ławica Airport constitutes an envelope of noise isolines with specified acceptable values, indicated separately for daytime and nighttime. The external zone is limited by: from the outside – a balanced sound level isoline of LAeq = 55dB for daytime and LAeq = 45 dB for nighttime (for noise generated by an aircraft landing, take-off and flight). In the case of noise from other aviation-related sources, the isolines assume the levels of LAeq = 50 dB (daytime) and LAeq = 40 dB (nighttime). From the inside, however, the zone is limited by a line constituting the envelope of the inner region of the restricted use area.

The internal zone of the area is limited by: from the outside – a balanced sound level isoline of LAeq = 60 dB for daytime and LAeq = 50 dB for nighttime (for noise generated by an aircraft landing, take-off and flight). In the case of noise from other sources related to aviation activities, the isolines assume the levels of LAeq = 55 dB (daytime) and LAeq = 45 dB (nighttime). A line running along the border of the airport area limits the zone from the inside.

The restricted use area of the Poznań-Krzesiny military airport is divided into three zones. Each zone strictly defines requirements on, among other aspects, the purpose of the land, the manner in which the land is used and tech-

nical requirements for constructions. Zone I is located in the area of Poznań, as well as the municipalities of Luboń, Komorniki and Kórnik. Zone II covers the city of Poznań, as well as the municipalities of Luboń, Kórnik, Mosina and Komorniki. Zone III involves the largest area, including Poznań, as well as municipalities of Luboń, Komorniki, Puszczykowo, Stęszew, Mosina, Kórnik, Kleszczewo and Środa Wielkopolska.

4. Research methodology

The method of statistical analysis has marginal importance in the process of property valuation. In everyday practice, the valuers employ it in an extremely limited extent. On the other hand, however, analyses of the property market based on mathematical statistics find many applications, as well as enable reliable and effective market characterisation established on unambiguous indicators. The most frequently applied methods based on statistical analysis include models, such as hedonic, regression, spatial analysis and artificial neural networks (Trojanek et al. 2017).

In the property market analyses, hedonic methods have been successfully used since the 20th century (Rosen 1974). The basic aim of such models consists in answering the question of how the analysed, specified factors influence the property value. The main idea of hedonic models involves the assumption that the price of a certain good (in this case – a property), is characterised by several selected attributes. As a result, the hedonic model allows determining the value of the analysed features, as elements of the whole, i.e. the property price. The assumed property characteristics, such as the level of aircraft noise or location, constitute the explanatory variables. The property price will result directly from the selected explanatory variables.

$$C = \beta_0 + \sum_{i=1}^{K} \beta_i X_i + u \quad (1)$$

where:
C – property price,
β – regression coefficient,
X – the value of the analysed attribute,
u – random error.

In the analyses of the property market using the hedonic models, the most commonly applied is the regression function, based on the natural logarithm, resulting from the possibility of changing the value of a certain feature proportionally to the changes of others. However, in the case of linear models, it is possible only to determine the influence of the selected feature's improvement (e.g. the finishing standard for all properties in the analysed set), without specifying the impact of the improvement in the standard of apartments with, for

instance, different surface areas. Further advantages of the logarithmic function consist in straightforward interpreting of coefficients, as well as eliminating the problem of random element variability (Trojanek 2014). Therefore, the following study is also based on a logarithmic model.

Moreover, the key issue consists in the selection of features that most significantly affect the property price. One of the basic functions of properties is their diversity, which entails, among other things, that attributes affecting the value of a given type of property are not necessarily relevant for premises of different types. In the case of residential properties, the most important features appear to involve location, neighbourhood, form of ownership, upper-floor location and surface area (Radzewicz & Wiśniewski 2012). The following study analyses an additional feature, defined in the property price – the level of noise emitted from air transport. Considering the above-mentioned assumptions, the hedonic function of the price may be presented in the following manner:

$$\ln(C) = f(\text{location, neighbourhood, the form of ownership, upper-floor location, surface area, aircraft noise}) \quad (2)$$

5. Results

To determine the impact of aircraft noise – imposed by the location of the property in the restricted use zone – on apartment prices, the paper collected information on the transactions of residential premises within the city of Poznań, from the first to the fourth quarter of 2020. The data were initially used to conduct a preliminary analysis of correlations between aircraft noise and the property market in 2020 in Poznań.

The analysis shows that only two transactions originate from the area located in the airport's immediate vicinity, namely the premises in Jeżyce, which are partly situated in the zone of the restricted use of the Poznań-Ławica Airport. A total of 168 transactions were recorded in the zones of limited external use in both Poznań-Ławica and Poznań-Krzesiny airports, the highest number of which occurred in Grunwald (57) and Jeżyce (41). Outside the restricted use zones of both airports, the study collected data on 1380 residential unit transactions, mainly from districts of Rataje (161), Nowe Miasto and Winogrady (145). In total, data on 1550 transactions were recorded, while the vast majority involved premises located outside the restricted zones (Table 2).

Table 2. The number of offers regarding residential units in each district of Poznań

District	Inside the zone		Outside the zone	Total
	Zone I	Zones II and III		
Central Poznań	0	0	111	111
Górczyn	0	35	86	121
Grunwald	0	57	80	137
Jeżyce	2	39	79	120
Łazarz	0	29	84	113
Nowe Miasto	0	0	145	145
Piątkowo	0	0	130	130
Rataje	0	0	161	161
Sołacz	0	8	55	63
Stare Miasto	0	0	109	109
Wilda	0	0	109	109
Winiary	0	0	86	86
Winogrady	0	0	145	145
Total	2	168	1380	1550

To initially verify the impact of aircraft noise on the transaction price, a median of prices was determined in districts, where the offers occurred within the restricted use zone (Table 3).

Table 3. The median of offer prices inside and outside the restricted use zone, including the districts of Poznań

District	Inside the zone	Outside the zone	The median difference (%)
Górczyn	6954	7679	-9.44
Grunwald	6242	6990	-10.70
Jeżyce	6298	7400	-14.89
Łazarz	5882	6990	-15.85
Sołacz	7950	8789	-9.55

In each of the analysed districts, the median of property transactional prices is lower among those located in the restricted use zone, compared to those located outside the zones. However, based on the median of prices, one cannot derive any significant conclusions about the influence of the analysed factors on the property price, as it does not include the most important features that significantly determine the price.

A multi-factor analysis of the price function was applied in order to include several analysed factors affecting the property price. With regard to property prices, the most frequently used is the hedonic method. Therefore, to determine the impact of the restricted use zone on property prices, the hedonic regression was conducted. The selection of variables applied in the model resulted, among others, from the availability of data. The study used the following variables: location, neighbourhood, the form of ownership, upper-floor location, surface area and aircraft noise (Table 4).

Table 4. The values of qualitative and quantitative variables applied in the model

Variable	Symbol	Characteristics of the feature
Location (district)	d_1 – Poznań Centrum, d_2 – Górczyn, d_3 – Grunwald, d_4 – Jeżyce, d_5 – Łazarz, d_6 – Nowe Miasto, d_7 – Piątkowo, d_8 – Rataje, d_9 – Sołacz, d_{10} – Stare Miasto, d_{11} – Wilda, d_{12} – Winiary, d_{13} – Winogrady	13 variables were assumed – if the property is located in a given district, it adopts the value of 1. For the remaining variables, the value amounts to 0.
Neighbourhood	s_1 – neighbourhood	One variable was assumed. If the apartment is located in a well-developed neighbourhood, it receives the value of 1. Otherwise, the value amounts to 0.
Form of ownership	w – ownership	If the apartment is the subject of ownership, it receives the value of 1. Otherwise, the value amounts to 0.

Table 4. cont.

Variable	Symbol	Characteristics of the feature
Upper-floor location	pp – upper-floor location	The variable assumes the value of 1 for a location on the first, or higher floors if the building has an elevator. Otherwise, the value amounts to 0.
Surface area	pow – useful floor area	Useful floor area measured in square meters.
Aircraft noise	hl – restricted use zone	Two variables of the feature were adopted. If the property is located in an area where aircraft noise exceeds 55 dB, it receives the value of 1. Otherwise, the value amounts to 0.

In the following stage, appropriate function parameters were estimated with the use of RStudio software. Both the property price included in the model, as well as the analysed attributes, were explanatory variables.

Table 5. Estimation of function parameters, dependent variable – price

	Coefficient	Standard error	T-value	P-value
constant	8.92497	0.08937	99.863	< 2.00E-16
d_1	-0.05911	0.03150	-1.877	0.06075
d_2	0.06738	0.03137	2.148	0.03189
d_3	-0.06613	0.03165	-2.089	0.03683
d_4	-0.02831	0.03195	-0.886	0.37577
d_5	-0.09761	0.03234	-3.018	0.00259
d_6	-0.07252	0.02965	-2.446	0.01455
d_7	-0.00577	0.03161	-0.183	0.85518
d_8	-0.09141	0.02849	-3.209	0.00136
d_9	0.17095	0.03890	4.394	1.19E-05
d_{10}	0.10581	0.03136	3.374	0.00076
d_{11}	-0.02647	0.03139	-0.843	0.39914
d_{12}	0.14069	0.03395	4.144	3.61E-05

Table 5. cont.

	Coefficient	Standard error	T-value	P-value
constant	8.92497	0.08937	99.863	< 2.00E-16
S1	0.08404	0.01501	5.598	2.56E-08
w	0.06381	0.02035	3.136	0.00175
pp	0.12829	0.01497	8.571	<2.00E-16
pow	-0.05606	0.02107	-2.661	0.00788
hl	-0.04578	0.02401	-1.907	0.05668

The analyses conducted on the basis of collected data did not allow for the identification of one of the coefficients for variable d_{13}, due to its absent differentiation. The difference between the observed values and the dependent variable defined by the standard error amounted to 0.2468, with 1528 degrees of freedom.

Based on the conducted analyses, it can be observed that in the examines period (2020), the residential property prices were significantly affected by their location in specified districts of Poznań. Location in the districts of Sołacz, Stare Miasto and Winiary was particularly important for the increase in prices. Moreover, while analysing the results, one can undeniably state that the price was significantly influenced by its closest neighbourhood and upper-floor location (Table 5).

Moving to the main purpose of this paper, the explanatory variable related to aircraft noise is statistically significant. The application of the hedonic regression based on the natural logarithm allowed for the identification of the percentage change in the difference of property prices with comparable characteristics, located in the area exposed to noise above 55 dB, as well as below this value. The coefficient of the feature (hl) assumed the value of -0.04578 (Table 5), which indicates that premises exposed to aircraft noise on average, adopt a value lower than 4.58%, compared to properties located outside the impact zone of the airport.

6. Discussion of the results

The study conducted within the framework of this paper constitutes one of the first studies related to the analysis of the impact of aircraft noise on the value of the residential properties in Poland. The vast majority of available studies involve the analysis of the impact of airport proximity, primarily in the United States (Cohen & Coughlin 2009, McMillen 2004), Western European countries (Püschel & Evangelinos 2012, Le Boennec & Salladarré 2017) and Canada (Maguire & El-Geneidy 2018).

A direct comparison of the obtained results with the previous studies may be restricted due to the differences in the location of the airport or the conditions of the local property market. The fact that the analysis covered a specific type of property should be taken into consideration as well. Taking into account the study (Trojanek et al. 2017) presenting the correlations between aircraft noise and prices of different types of properties within a single market, it should be emphasised, that the impact of this feature may vary. As a consequence, the obtained results and conclusions formulated on their basis, apply solely to the residential properties.

However, referencing to the existing studies which summarise the previous research on the impact of aircraft noise on the property value (Wadud 2013, Kopsch 2016, Batóg & Foryś & Konowalczuk 2019), one can notice a certain similarity between the results obtained in this study and the literature on the subject. The conducted analyses allowed for the identification of a statistically significant, negative impact of the airport's proximity on the property value, similarly to recent studies (Zheng et al. 2020, Bełej et al. 2020, Cellmer et al. 2019).

The analysis was performed according to the modified methodology, relating to the previous analyses (Huderek-Glapska & Trojanek 2013, Trojanek et al. 2017). Within the framework of this study, the variable related to aircraft noise was defined by two variables. As a result of preliminary analyses, it was possible to identify that, due to the criteria by which the existing restricted use zones in both local airports are designated, the ones located in areas where the value of aircraft noise exceeds 55 dB are particularly exposed to noise. In connection with the adopted criteria, we have determined how the location in the area in which the value exceeds 55 dB affects the transaction prices.

The analyses were conducted based on the 2017 noise map of Poznań. The obtained results are properly justified, there are some certain limitations to the solution mainly resulting from the lack of data. In this situation, the problem may arise in connection with the validity of data, as the noise maps are prepared in a five-year perspective. Therefore, the analyses were performed in accordance with the available materials, which, however, are not necessarily consistent with the actual state of affairs during the research. It is necessary to consider the fact that the acoustic conditions in the city may change over time as a result of, among other things, the intensification of air traffic. The obtained results may not be valid in the following years, due to modifications in actual conditions. Moreover, the restrictions of the presented method may be related to the fact that the impact of proximity to airports in other regions/cities of Poland may be different as it depends on local conditions. Finally, it is worth noting that the research area covers several districts of Poznań, which means it doesn't take up much area. Consequently, it is difficult to draw universal conclusions that could

be formulated for other larger study sites. Monitoring of the impact of aircraft noise on the property market should be conducted in a continuous and systematised manner, which enables the observation of dependencies occurring over a longer period of time.

7. Conclusions

1. The application of a logarithmic model allows for determining the percentage difference in the transaction price of a residential unit, located within a zone particularly exposed to noise (55 dB), as well as outside that zone.
2. Within the local property market, aircraft noise constitutes a statistically significant attribute reducing the prices of premises.
3. Properties are considered to be special goods. Their price is influenced by several of factors, resulting directly from the local character of the property market.
4. The manner in which the selected attributes interact with one another may vary, depending on the type and spatial extent of the property market. The impact of relevant factors on price may also vary with time and local planning, social and economic conditions.

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The Impact of Urban Public Transport on Residential Transaction Prices: A Case Study of Poznań, Poland

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Abstract: This study aims to determine the magnitude and nature of the impact of public urban transport accessibility on the value of residential properties in Poznań. The study was based on 2561 residential transactions completed within the study area in 2020. The input data obtained from the Board of Geodesy and Municipal Cadastre "GEOPOZ" were analysed statistically and spatially. The main part of both the spatial and the statistical analysis was performed using the hedonic pricing method (HPM)-OLS (ordinary least squares) and WLS (weighted least squares). The use of statistical tools enabled the finding of evidence to prove that the convenient accessibility of trams is positively related to housing prices. This has also been confirmed by previous research works conducted in other parts of the world. However, the collected data did not enable the identification of statistically significant relationships between housing prices and the distance from bus stops. The study also attempts to use spatial choropleth maps to clearly illustrate the mechanisms within the local housing market.

Keywords: hedonic regression; property market; public transport; price map

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1. Introduction

1.1. Urban Public Transport

Public transport systems, due to their specificity, perform a basic function that is necessary for the business, economic, and social development of large urban centres [1]. Public transport directly affects both the reduction in traffic congestion and the quality of life of local communities. It also reduces social differences resulting from mobility constraints on a part of the population. Urban public transport managers should pay particular attention to the interests of poorer people, who often have very limited mobility. An important role of urban transport should be to bridge social divides [2–4]. Factors such as mobility and the widespread accessibility of urban public transport affect numerous aspects of daily life, and social interactions contribute significantly to the inclusion of people with reduced mobility such as, i.a., the elderly [5]. Moreover, it should be noted that the development of the public transport sector leads directly to a reduction in the environmental impact of the transport sector, i.a., because almost 20% of CO_2 emissions comes from road traffic [6,7]. From an economic perspective, the relationship between access to public transport and the competitiveness of economic entities, regardless of the economic sector in which the company operates, is of extreme importance. Factors relating to the accessibility of work for excluded people should be taken into account in the defining of a transport policy by the competent authorities [8,9]. Finally, the accessibility of high-quality urban transport systems also affects the property market and plays a fundamental role in the process of determining the value of properties. The urban transportation infrastructure can significantly impact the attractiveness of locating properties near stations and can improve the accessibility of these locations [10–12]. Due to its significance, the attribute related to the accessibility of the transport infrastructure in terms of the property market analyses has

been a factor gaining in importance in recent years and has become the subject of many research works [13–18].

Apart from the many aforementioned advantages, urban transport networks also have certain limitations, mainly due to the high costs related to construction, operation, and maintenance. For instance, the total cost of the 3.3 km tram line in Poznań that is currently under construction (including reconstruction of the road system) from the Wilczak terminal to the Naramowice terminal stop is estimated by local authorities at PLN 430 million. According to the 2019 Annual Report of the Municipal Transportation Company, the total costs, including, but not limited to, operating expenses or financial expenses, significantly exceed total revenue, including, but not limited to, net revenue sales. As a consequence, urban public transport generates a loss that affects the ambiguous perception of the prospects for its development, especially by local communities. Usually, public officials and planners justify the development of investments related to the transport infrastructure by the possibility of compensating for the loss incurred through increasing the value of the residential properties located in the vicinity of the investment [19–21]. The vast majority of the existing studies that are related to urban transport concern the analysis of the direct costs that play a significant role in the urban planning process. Those studies usually concern pollutant generation, noise, and road congestion [22–25]. On the other hand, the issue related to the external benefit analysis is usually not addressed in the social and economic studies concerning such types of investment. From the perspective of the problem presented, the identification of the nature and magnitude of the impact of the transport infrastructure on the value of properties is an extremely important issue. Therefore, the most important research question of the study was formulated: How does public transport affect housing prices?

1.2. Residential Housing Market

The market value of a property depends on several individual and property-specific characteristics that can generally be divided into physical and economic factors. The first group includes attributes such as the dwelling size or the topography of the plot of land, while the second group includes attributes such as the demand and supply size and the employment structure within the local property market. An attribute of particular importance for residential properties located in urban areas is the location, accompanied by its derivative—the immediate neighbourhood [26–28]. Location is usually a highly significant attribute for potential buyers, and it is usually considered in terms of the accessibility of the service infrastructure (e.g., shopping centres and cultural facilities), the social infrastructure (e.g., kindergartens and nurseries), and the transport infrastructure (e.g., bus stops and tram lines) [29]. In terms of location, the factors that determine the quality of the immediate neighbourhood are also relevant. They include, among other things, the accessibility of biologically active areas that favour recreation and enable active leisure [30,31] as well as facilitate the reduction in pollution from road transport [32–34].

The analyses conducted on the level of the property market, related both to the process of property valuation and the analysis of mechanisms within this type of market, are performed using the statistical methods applied in mathematics [35–39]. Among the tools applied, two fundamental groups of methods can be distinguished: the basic and the advanced ones. The group of advanced methods, which constitute the basis for this study, include the following techniques: Artificial Neural Networks (ANN), the Contingent Valuation Method (CVM), the Hedonic Pricing Model (HPM), and the techniques related to spatial analyses that have become increasingly important lately [40]. Two methods that are most frequently used for the identification and assessment of non-marketable goods include the Hedonic Price Method (HPM) and the Contingent Valuation Method (CVM). The main difference between those methods stems from the fact that, as part of the CVM method, the values of factors that cannot be directly valued by the market mechanism are determined based on the results of surveys that define preferences in a detailed group of respondents [41]. Given the basic aim of the study and the reference literature, it can

be assumed that the market participants' preferences are, as a rule, directly reflected in the housing price. This assumption is justified by the fact that potential buyers prefer apartments with convenient transport accessibility, which enables them to get to other parts of the city without too much trouble. Therefore, the HPM is an appropriate and necessary analytical technique to perform the property market analysis considering the selected attributes. It should be noted that this method additionally includes one of the most important attributes of property heterogeneity, which works very well in this type of analysis, and the obtained results can be considered to reliably reflect the actual situation on the market. Moreover, this study was conducted using spatial analysis, which guarantees a higher complementarity of the results obtained.

It should be noted that the HPM is used in many other scientific fields, such as that of the social [42–44] and the natural [45,46], as well as in the analysis of other types of markets [47–50]. The use of this method to determine the effect of transport accessibility on the value of housing units is an extremely important study, although there are many examples of the application of this method in property market analyses. Due to this method, this study may be a reference for comparable analyses that determine the impact of the proximity of developed transport infrastructure on property value, especially in Poland. Given the accuracy of the HPM characteristics in the literature, the study may not be considered novel or innovative; however, it may be key in determining the external benefits of transport infrastructure investments. The method of interpreting the results used in the study, based on spatial analysis combined with statistical analysis, may constitute an innovative approach to real estate market analyses and may find wide application due to the simplicity of interpreting the results.

2. Materials and Methods

2.1. Study Site and Data

The presented study was conducted in Poznań (the capital of the Wielkopolska Voivodeship), the area of which is 262 km^2. Poznań has fundamental importance for the neighbouring municipalities and directly determines their economic and social development. This city is located in the western part of Poland. According to the Statistics Poland data, Poznań is inhabited by 533,830 people, of whom the majority are women—284,587, and the number of men is 249,243 (as of June 2020). People of working age constitute a decisive advantage in the demographic structure (59%); 14% of the city population are people in pre-working age (below 15 years of age); and the remaining 26% are people in post-working age.

At the end of 2017, the total length of the communication lines was 1872.70 km. The length of all the tram lines was 229.33 km, while the bus lines amounted to 1118.14 km within the city and 754.56 km within the agglomeration. The total length of the routes was 768.90 km, of which the length of the bus routes within the city was 339.11 km and 429.79 km outside the city, while the length of the tram routes was 68.85 km. As a part of the urban transport, a special role is played by the Poznań Fast Tram (PFT) which is operated by 4 daily lines running at high frequency during rush hours (every 6 min for line nos. 15 and 16 and every 10 min for line nos. 12 and 14). The PFT route is also operated by one night line, no. 201. According to the Sustainable Development Plan of Public Collective Transport for the City of Poznań for 2014–2025 (as of November 2018), the public transport organised by Poznań has 20 tram lines, 53 daily bus lines, and 21 night bus lines within the city. Moreover, 55 suburban lines are operating in the agglomeration based on inter-municipal agreements. The participants of the public urban transport run by the Public Transport Authority can use 2232 bus stops—almost half of the stops (1162) are located within the city. Tram stops play a special role; there are 239 tram stops and 52 bus/tram stops within the city (Figure 1). According to data related to city statistics, the number of Poznań Electronic Agglomeration Cards (PEKA), which is a fee carrier, amounted to 714. There were four thousand at the end of 2020. The higher number of declared users of public transport than the total number of Poznań residents may indicate the additional

high importance of this form of transport for residents of neighbouring communes and people not registered in Poznań.

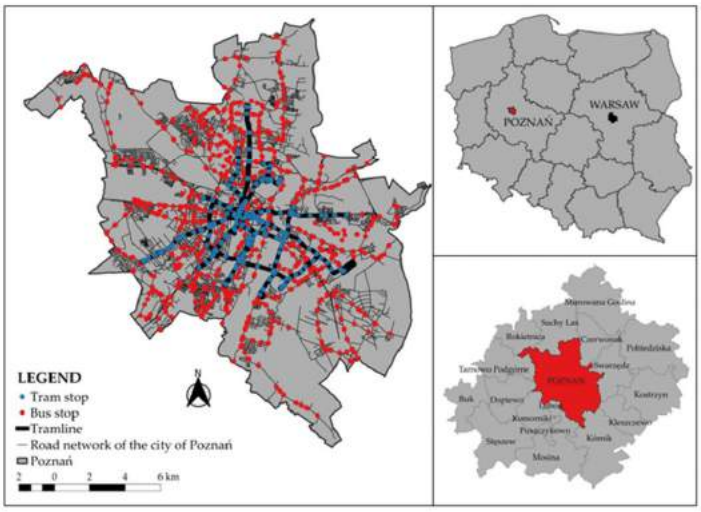


Figure 1. Location of the research facility—Poznań.

The source data obtained from the Board of Geodesy and Municipal Cadastre in Poznań are the basic group of data underlying this study. These data concern market transactions of housing units that were concluded in Poznań in 2020—2561 transactions in total (Figure 2).

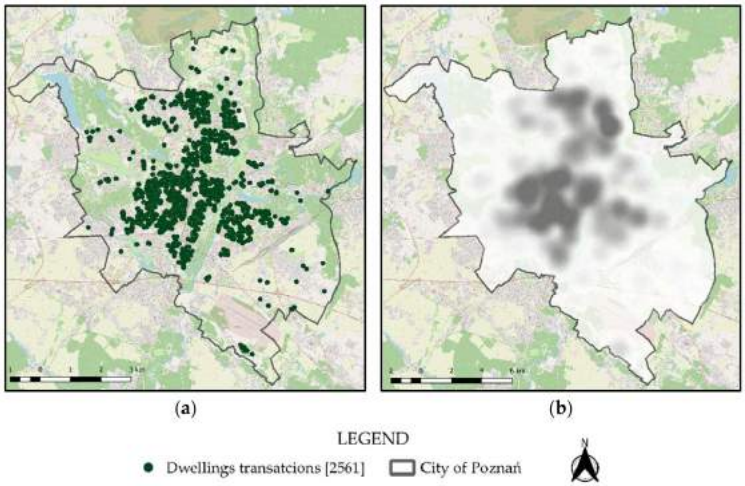


Figure 2. (**a**) Location of housing units analysed. (**b**) The size of transactions within the analysed area.

As part of the initial analyses, the acquired data were reviewed for their usefulness. This process involved eliminating from the database the transactions that were concluded

under specific, special, and non-market conditions (e.g., property transactions for purposes of bailiff auction or sale in enforcement proceedings). The transaction data obtained from the Board of Geodesy and Municipal Cadastre in Poznań are reliable and credible sources of information concerning the real and current situation on the property market because they come from notarial deeds. The characteristics of this type of data make them widely applicable in a variety of property market analyses.

The basic information gathered in this database includes information for each property regarding transaction price, transaction date, and area of housing unit, along with the area of the ancillary rooms and information on which floor the housing unit is in the building. A key problem of this type of data is the lack of their complementarity compared to the detailed characteristics of the basic attributes affecting the value of the property, such as the immediate environment, the technical condition of the building, or the standard of finish of the housing unit. An attempt to identify and specify the attributes that materially affect the value of housing units based solely on information collected in this register cannot be considered a presumptively acceptable approach given the unique nature of the property, whereby value is affected by several attributes that are not defined in the register. To alleviate this problem, the source data were supplemented with additional characteristics of the analysed residential properties, such as the location details or the characteristics of the immediate neighbourhood.

2.2. Methods

The breakthrough concepts related to the process of determining the characteristics of how selected factors affect the value of the property, the foundation of which is the HPM, appeared in the early 20th century. A pioneering study based on the HPM is a documented study in which G.A. Hass formulated an agricultural land price model in 1922 [51]. In the following years, this method gained more and more importance, and as a result, it was used, among others, for defining the relationship between air pollution reduction and residential property prices [52]. The theoretical framework of this method was specified and detailed by authors such as Lancaster [53], Rosen [54], and Maclennan [55].

Within local conditions, the HPM was the basic tool for determining, e.g., the nature of the impact of selected factors that are related to noise generated by air traffic or the accessibility of urban green areas on the value of residential properties in several major Polish cities, such as Warsaw [56,57], Krakow [58,59], or Poznań [60,61]. On the other hand, in terms of advantages (transport accessibility) or disadvantages (emitted noise) resulting from the accessibility of the public transport infrastructure on the value of residential properties, the analyses were conducted mainly in the United States [62–65], the southern European countries [66,67], and Asia [68–70].

The HPM is a method that investigates the relationship between the price of a given commodity, which in this type of market is property, and its most important characteristics. Market participants make investment decisions that are typically based on detailed property characteristics and an analysis of their utility. When it comes to a housing unit, the attributes that most frequently determine its investment attractiveness include the usable floor area, the number of rooms, including the associated premises, the age, and the technical condition of the building, as well as the availability of additional amenities, such as a parking space or access to a passenger lift [40,71]. Location is also a factor of extreme importance. It is usually considered in terms of the accessibility of, among others, public utility facilities, service facilities, and recreational facilities [56,72]. Moreover, other types of environmental and social factors that are defined by location and the condition of the immediate neighbourhood affect the price that a property can fetch during a market transaction [73,74].

The most important issue when using the model that was built using the HPM is to answer the question of how the selected factors adopted into the model affect the value of the residential property. The essence of the HPM model is the assumption that the property price is explained by several defined characteristics. The model obtained as a result of the statistical analysis makes it possible to specify the values of the analysed factors that

ultimately constitute specific components of the total price. The explanatory variables are characteristics included in the analysis that describe the property, e.g., the area and the transport accessibility [40,41,75]. According to the above assumption, the price of a housing unit can be determined in the form of a standard regression equation.

$$p = \beta 0 + \sum_{i=1}^{K} \beta i \, X_i + u \quad (1)$$

where p is the housing price, β is the regression coefficient, β_0 is the regression constant, X is the property attribute, and u is the standard error.

A regression function based on the natural logarithm is most frequently used during property market analyses using the HPM. This type of solution provides a reasonable solution to the problem that is related to the inability of the selected attribute to change in value in proportion to changes in the other factors in the case of a linear model. Consequently, the linear model only enables specifying the impact of the improvement or deterioration of a specific attribute, e.g., the technical standard, for all the residential properties in the adopted dataset. Unfortunately, these models do not identify the impact of increasing or decreasing the quality of an attribute for housing units with, for example, varying locations. The very process of interpreting the regression coefficients and addressing the problem of random component variation is also an important advantage of models that are based on the logarithmic function [57]. Regarding the conditions presented, the present statistical analyses were performed based on a logarithmic model.

In this study, two basic variants of hedonic regression were used: OLS (ordinary least squares) and WLS (weighted least squares). In the first stage, the OLS regression was performed, under which the WLS regression was performed in the following stages: performance of an auxiliary regression in which the squares of the residuals were dependent variables, while the input independent variables plus their squares were independent variables. In the next section of this article, a series of weights was created from the values derived from the hedonic regression. Finally, the original model was estimated using the WLS method [40].

2.3. Variables

The most important aspect that is related to the analysis of the property market is the selection of the appropriate characteristics that have a decisive influence on the price of the residential property. Heterogeneity is one of the fundamental characteristics of the property; it results, among other things, in the fact that factors that are relevant to one type of property may be of marginal importance in a property of another type. For housing units, the variables can be grouped into four categories of attributes that relate directly to the characteristics of a dwelling, the neighbourhood, and the environment as well as to the social, economic, and planning conditions. Given the type of housing units and local conditions, each of the defined groups includes several specific attributes (Table 1).

Given the characteristics of the source data, the literature review, and the fundamental assumption of the conducted analysis within the first group (attributes of a dwelling), the following attributes should be distinguished: floor area, floor location, presence of a basement, number of rooms, height of a building. The most important variables that were adopted for the analysis among the other groups were attributes related to the accessibility of transport, schools, and recreational areas. Ultimately, the study did not include extremely important attributes that are related to housing characteristics, such as standard of finish or type of dwelling. For an attribute that is related to the standard of finish, the available data do not provide a way to determine the status of that attribute for each property listed in the database. On the other hand, the attribute referring to the type of dwelling was omitted because a vast majority of transactions concerned housing units located in multifamily buildings, while all other housing units, e.g., in single-family buildings, were of marginal significance within the local market. All the characteristics that can influence

the price cannot be included in the model because too many variables used during the model-building process can reduce its cognitive quality. On the other hand, however, an insufficient number of attributes may lead to a failure to take into account those factors that can significantly influence the price of the residential property. Additionally, as a result of constant cooperation with real estate agencies in Poznań, we were able to select a group of features that are extremely important for the local real estate market from the features presented in Table 1. According to the presented assumptions, the hedonic function of the housing price can be represented as follows:

$$\ln(p) = \mathbf{f}\,(\text{structural features, transport accessibility, location}) \quad (2)$$

Based on the defined attributes that were adopted for the model, the characteristics of the analysed residential properties were performed; this constituted the next part of the study. The process of defining the variables was performed according to the adopted criteria. The property was specified based on the information collected in the acquired GEOPOZ database and the measurement of the actual distance for specific attributes using QGiS 3.16.1 software and our own analyses.

Table 1. Categories of variables created based on the literature on the subject.

Category	Variable	Author
Characteristics of a dwelling	Surface area	Čeh et al. [76]
	Number of rooms	Liu et al. [77]
	Type of a housing unit	Park et al. [41]
	Age of a building	Wu et al. [78]
	Parking space/garage	Ko et al. [79]
	Upper-floor location	Szczepańska et al. [80]
	Type of building construction	Ooi et al. [81]
	Form of ownership	Marano and Tajani [82]
	Accessibility of basement	Ottensmann et al. [83]
	Standard of finish	Tomal [84]
	Energy efficiency	Zancanella et al. [85]
Characteristics of neighbourhood	Distance to the centre	Jasińska and Preweda [86]
	Distance to the primary schools and kindergartens	Sah et al. [87]
	Access to public transport	Cordera et al. [88]
	Distance to shops	Heyman et al. [89]
	Distance to recreational areas	Sikorska et al. [90]
	Bothersome neighbourhood (airport, etc.)	Kopsch [91]
	Distance to industrial zones	Wittowsky et al. [92]
Characteristics of Environment	Distance to lakes	Yuan et al. [93]
	Distance to green areas, parks	Łaszkiewicz et al. [94]
	Distance to legally protected areas	Pearson et al. [95]
	Distance to other valuable natural areas (rivers, mountains, etc.)	Xiao et al. [96]
	Air pollution	Chen et al. [97]
Characteristics of local social, economic and planning conditions	Amount of tax	Munro and Tolley [98]
	Demographic structure	Lai [99]
	Employment opportunities	Ding et al. [100]
	Prospects of economic development	Perdomo [101]
	Increase in revenue generated	Feng [102]
	Dynamic business development	Md and Sheikh [103]
	Occurrence of planning barriers	Hussain et al. [104]

Number of rooms

This is a characteristic that should be considered during property market analyses, along with the area of the housing unit. The number of rooms determines how the premises will be developed. Too many rooms in a relatively small usable area may lead to the

unfavourable arrangement of rooms, which usually results in the worsening of the living standard of the residents. On the other hand, a small number of rooms in a residential area may lead to underutilisation of the functional capabilities of the premises. In the analysed transaction dataset, the variable has varied values ranging from 1 to 8, while the average number of rooms is equal to 2.94.

Surface area

The surface area has a key role to play in the price of residential properties. It is assumed, in principle, that the unit price of a housing unit (per 1 m^2) with a smaller surface area should be higher in relation to a comparable housing unit but with a larger surface area. As with other characteristics, however, this variable depends to some extent on local conditions. The abovementioned principle may not be correct under certain conditions. Information concerning the surface area of the property was obtained from the database of the Board of Geodesy and Municipal Cadastre "GEOPOZ". With regard to the actual surface area of the residential properties within the analysed set, the variable takes different values ranging from 13.70 m^2 to 212.00 m^2, while the average surface area is equal to 54.14 m^2.

Floor

The location of a housing unit on a particular floor in a building plays a key role in terms of safety and accessibility. These factors are often of key importance to buyers, meaning that the floor determines the transaction price to some extent. For buildings of a relatively low height, higher prices are achieved by housing units located on the first and middle floors. However, this is not the case in high-rise buildings with passenger lift access. In this type of building, housing units located on higher floors are definitely more valued, i.e., they have higher prices. As with the surface area, the floor was determined based on information obtained from the acquired database. In the adopted transaction dataset, one of the housing units was located on the 17^{th} floor. On the other hand, the minimum attribute value was 1 for one of the housing units located on the floor below the ground floor. In contrast, the average value across the dataset was 2.63. With respect to the characteristics of the variable, it should be investigated together with the height of the building in which the housing unit is located.

Number of associated premises

The presence of associated premises, such as a basement, storage room, or garage is an attribute that, together with, i.a., the height of the building or its technical condition, belongs to the group of variables that are directly related to the characteristics of a housing unit. A balanced comparison of two comparable housing units that differ in terms of the presence of associated premises may be unjustified, which is very frequently confirmed by the price. The number of associated premises was included in the analysis due to its significant importance within the local property market. The variable for each residential property was specified based on the transaction data collected. The average value of the attribute was 0.37; the maximum value of the attribute—4 associated premises—was identified for one housing unit.

Access to public transport

This is the most relevant variable in terms of this study. Public transport has many benefits; however, the most important one seems to be the ability of non-motorised users to travel to any part of the city. Moreover, this type of transport guarantees low travel costs and, in the case of cities with heavy car traffic, it reduces travel time. In the analysis, access to public transport was considered in two ways. Public transport in Poznań is operated by the city's buses and by tram network. Therefore, the distance from the housing unit to the tram stop and bus stop was measured separately in the analysis. As a result of this type of division, two variables were distinguished within this attribute. The measured value of both variables represents the actual distance that an individual has to travel to get from the housing unit to the bus or tram stop using local pedestrian routes. For the analysed

transactions, the average distance to the nearest bus stop was 210.93 m, whereas to the nearest tram stop was 690.68 m. The minimum distance per housing unit was 15.07 m and the maximum distance was 7125.34 m for tram stops and 11.93 m and 1420.35 m for bus stops, respectively.

Distance to the Warta River

The natural landscape defined as a public good can significantly improve the perception of a highly urbanised urban space. As a result of the dynamic development of society, people in most social groups strive to emphasise the high quality of the environment, and they are willing to bear higher costs to preserve or enhance the natural aesthetic value of the urban landscape. Urban water objects, such as rivers or lakes, provide residents with clean and humid air that is necessary, especially when it is very hot. Furthermore, these objects guarantee a landscape with a low density of buildings, which is necessary to eliminate many of the stressors that play a harmful role in modern societies. The Warta River plays a special role in the study area and its accessibility was included in the analysis. The average actual distance to the river for the analysed residential properties was 2724.32 km. The maximum distance for one of the housing units was 9330.01 km, while the minimum value was 97.98 m.

Distance to primary schools and kindergartens

This is a key attribute, especially for young families with children. For older students attending secondary school, the location of their housing unit near their school is not as important because they can get to school using public transport. In the case of a group of younger students, the use of public transport is quite limited, with transport for them being provided with all the necessary precautions in place. Usually, however, parents choose to transport their children on their own, which determines the location of the housing unit within a convenient distance from the school. The analysis included the accessibility of a specific group of this type of infrastructure that is defined by primary schools and kindergartens. The actual average distance to the nearest educational institution measured using geo-information tools for all housing units was 673.55 m. The minimum distance was 6.09 m, and the maximum distance was 4387.43 m.

Distance to the centre of Poznań

This is a variable that is a component of a broader concept (location) of which it is also a derivative. It can be assumed that residential properties that are located in the very centre of big cities reach much higher prices compared to housing units located in the peripheral parts of the cities. For a certain type of potential buyers, this principle may not necessarily be true, as a certain part of the population prefers housing units that are far from the noise of the centre of most large cities. A particularly important role for this group of market participants is played by excellent public transport that guarantees convenient access to the city centre. The variable was determined by measuring the actual distance of the housing unit from the centre of Poznań. In the analysed dataset, the average value of the measured attribute was 3699.15 m; the housing unit located farthest from the city centre was at a distance of 11,311.75 m; and for one of the housing units located in the city centre, the minimum value of the attribute was 111.70 m.

Distance to urban green areas

In the case of large cities with high levels of urbanisation, such areas provide a range of benefits to residents in terms of important ecosystem services such as noise reduction, improved air quality, and the mitigation of extreme temperatures. Furthermore, they serve important functions in terms of their impact on the health and well-being of the residents. An additional advantage of such areas is the possibility of physical activity and recreation in nature in a highly urbanised landscape. Urban green spaces are a common social good that is especially valued in large urban centres by most social groups, especially the elderly, children, and physically active people. The average distance to the green area for the

analysed residential properties was 536.71 m; the minimum distance was 8.47 m; and the maximum value was 5539.09 m.

Distance to the shopping centre

Shopping centres appeared in Poland in the late 20th century, steadily gaining in importance throughout their operation. Large sales facilities have permanently entered the landscape of Polish cities, and during the last two decades, an intensive increase in the number of such facilities could be observed. Poznań is at the forefront of Polish cities in terms of both the number of facilities and the sales space. It is worth noting that shopping centres have evolved since their beginnings and in most cases have become almost self-sufficient facilities able to meet all the needs of customers and keep them entertained for many hours. Thanks to their characteristics, they are relevant to the immediate neighbourhood and condition the economic development and thus directly impact the property market. The average real distance to the shopping centre in the analysed set of properties was 899.49 m; the maximum distance was 7468.94 m; and the minimum distance was 31.97 m.

3. Results

To accurately determine how accessibility affects the value of housing units, the analyses were conducted in two stages. First, the collected data were subjected to preliminary verification based on spatial analysis, whose basic assumption was to define spatial regularities in relation to the analysed attribute. The most significant part of the study, which complements the spatial analysis, was based on multivariate statistical analysis performed using the HPM.

3.1. Spatial Analysis

The initial analyses were performed primarily using QGiS software and MS Excel, allowing for a straightforward interpretation of the results. Due to the way the analysed attribute was described in the study, this part of the analysis was divided into two groups. The accessibility of bus stops was considered in the first stage. The transactions accepted for analysis were classified into six groups defined by the distance one has to walk from a given housing unit to a stop of a given type. Considering the structure of the bus stops in Poznań, the following classification criteria were adopted: <100 m, 100–200 m, 200–300 m, 300–400 m, 400–500 m, and >500 m (Figure 3).

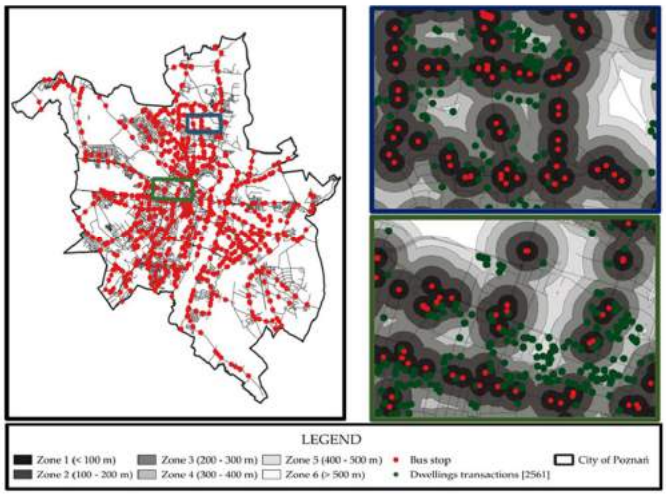


Figure 3. Classification of transactions based on the distance to bus stops.

Basic descriptive statistics, such as mean and standard deviation, were calculated for each of the groups in question. These statistics were formulated for both the explanatory variables and the dependent variable (Table 2).

Table 2. Descriptive statistics of dependent and independent variables across groups (bus stop).

	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6	
	Mean	Σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
Price (PLN/m^2)	7170.05	1654.80	6993.44	1588.99	7120.34	1748.98	7602.56	1857.10	7207.53	1991.29	6225.96	1181.38
Number of rooms	2.81	1.01	3.07	1.04	2.92	1.08	2.79	1.15	2.87	1.12	2.87	0.92
Surface area (m^2)	51.32	19.96	53.92	21.37	54.36	23.86	54.60	25.94	59.62	29.81	60.04	29.48
Floor	2.87	3.21	2.70	2.64	2.69	2.55	2.39	1.98	1.74	1.51	2.30	1.46
Associated premise	0.33	0.52	0.42	0.59	0.37	0.59	0.36	0.53	0.43	0.63	0.20	0.56
Distance to tram stop-m	671.42	984.93	628.04	830.56	527.55	583.27	743.34	924.17	1038.06	1085.99	1631.02	700.13
Distance to bus stop-m	65.31	23.86	151.72	28.31	241.98	27.21	340.58	27.49	442.11	30.47	591.21	104.88
Distance to Warta River-km	2910.11	1603.23	2756.53	1512.43	2661.50	1505.37	2530.20	1,56.42	3100.32	1848.53	2085.00	1865.95
Distance to primary school and kindergartens-m	644.38	513.46	634.70	471.93	663.77	480.42	652.85	415.33	877.30	807.86	1030.07	599.86
Distance to the centre of Poznań-m	3775.99	1888.13	3704.42	1642.72	3476.51	1663.07	3395.58	1916.00	4267.22	2100.28	4750.79	1358.66
Distance to urban green areas-m	562.37	493.44	468.43	408.75	536.72	474.93	535.80	495.32	861.46	795.77	659.87	733.93
Distance to shopping centre-m	965.35	959.75	867.99	771.47	777.30	594.73	845.71	643.93	1298.85	843.40	1255.08	595.23
Number of observations	491		943		593		306		119		109	

The median prices of the residential units in the examined groups, determined by the distance criterion, changed significantly in the evaluated transaction dataset and reached the lowest value in the last group (Figure 4).

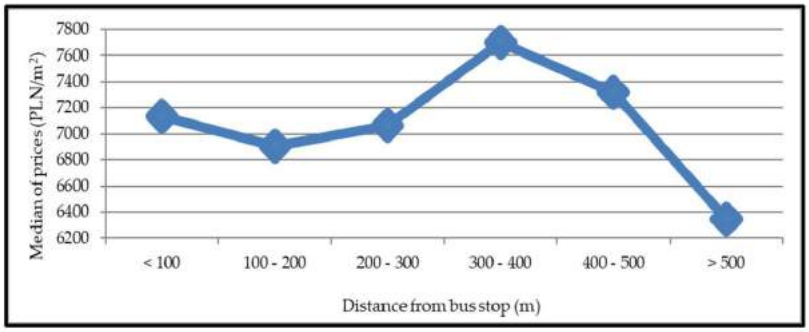


Figure 4. Median prices by group (bus stop).

The second stage of this section of the study was carried out in the same way. The only difference was the method of interpreting transport accessibility, this time defined by the distance to tram stops. Due to the significantly smaller network of tram stops compared to bus stops, the assumed classification criteria were modified and formulated in the following form: <200 m, 200–400 m, 400–600 km, 600–800 m, 800–1000 m, and >1000 m (Figure 5).

Basic descriptive statistics, such as mean and standard deviation, were determined for the groups analysed. These statistics were formulated for both the explanatory variables and the dependent variable (Table 3).

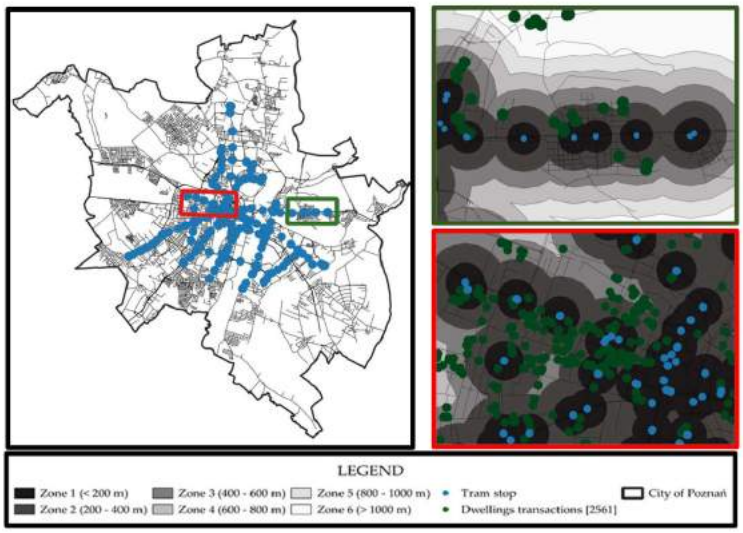


Figure 5. Classification of transactions based on the distance to tram stops.

Table 3. Descriptive statistics of dependent and independent variables across groups (tram stop).

	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6	
	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	Σ	Mean	σ
Price (PLN/m^2)	7348.85	1893.52	7228.31	1777.02	6833.13	1546.40	7068.00	1482.24	7189.75	1731.14	6826.19	1420.52
Number of rooms	2.83	1.15	2.84	1.02	3.20	1.02	3.02	0.90	2.78	0.92	3.04	1.09
Surface area (m^2)	54.19	25.90	51.69	19.16	54.37	17.87	48.07	15.23	48.06	19.83	61.46	29.54
Floor	3.03	2.98	2.73	2.48	2.80	2.93	2.71	2.96	2.73	2.73	1.89	1.63
Associated premise	0.35	0.56	0.39	0.59	0.43	0.61	0.33	0.51	0.33	0.56	0.34	0.56
Distance to tram stop-m	129.31	45.91	288.54	58.36	483.00	53.74	707.06	60.08	881.16	55.08	2014.34	1140.76
Distance to bus stop-m	161.84	98.37	214.71	98.98	200.36	113.40	182.61	112.47	201.57	111.62	277.81	191.17
Distance to Warta River-km	2196.24	1245.89	2319.43	1171.62	2787.24	1271.36	3560.04	1435.54	3546.87	1674.61	3390.80	2214.14
Distance to primary school and kindergartens-m	501.39	365.79	604.90	416.14	581.01	383.03	661.81	403.21	727.11	341.56	1023.27	718.19
Distance to the centre of Poznań-m	2561.90	1393.76	2919.39	1316.67	3783.15	1223.05	4608.42	1025.09	4484.23	823.31	5595.28	1626.24
Distance to urban green areas-m	384.58	282.37	472.16	314.84	506.54	328.00	519.57	313.75	539.32	315.69	831.14	860.26
Distance to shopping centre-m	753.38	541.69	803.69	516.97	864.68	560.55	886.69	524.86	773.16	511.02	1272.60	1280.58
Number of observations	567		812		350		178		138		516	

The median prices of the residential units in the examined groups, determined by the distance criterion, changed significantly in the evaluated transaction dataset and reached the highest value in the first group (Figure 6).

The spatial analysis makes it possible to observe the initial relationship between the transaction price and the accessibility of the transport infrastructure. However, based on this type of analysis, no statistically significant conclusions can be drawn regarding the impact of the availability of the transport infrastructure on housing prices as it does not consider other important characteristics that can significantly determine the price of a housing unit in the local property market.

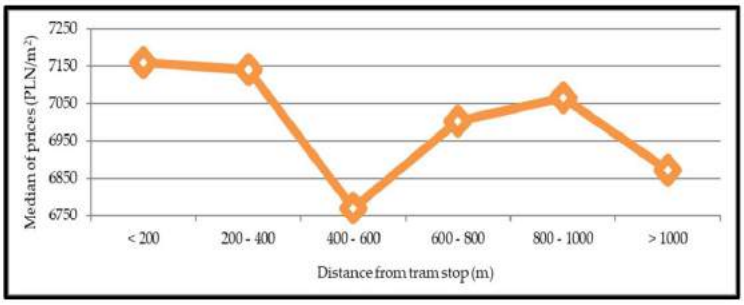


Figure 6. Median prices by group (tram stop).

3.2. Statistical Analysis

The characteristic attributes analysed in this study included the structural features of the housing unit (number of rooms, floor area, floor, and the accessibility of associated premises) and the attributes related to the location of the housing unit (access to schools, access to urban green areas, distance to the centre of Poznań, distance to the shopping centre, and distance to the Warta river). Regarding the research objective, the model assumed a feature related to transport accessibility defined by two variables: distance to a tram stop and distance to a bus stop. The variables adopted were selected for the model based on the data availability and the local property market characteristics. In the first stage, the assumed variables were defined to enable their use in the model (Table 4).

Table 4. Characteristics of qualitative and quantitative variables applied in the model.

Feature	Symbol	Feature Description
Price	p	Housing price (PLN/m^2)
Number of rooms	R1 (up to 2 rooms) R2 (3 to 5 rooms) R3 (more than 5 rooms)	3 variables are used in the model; if the housing unit has a given number of rooms, it is assigned the value of 1; otherwise, it is assigned the value of 0.
Surface area	SA	Surface area of the housing unit-m^2
Floor	F1 (up to the 2nd floor) F2 (3rd to 5th floor) F3 (above the 5th floor)	3 variables are used in the model; if the housing unit can be classified under one of the aforementioned floor level classes, it is assigned the value of 1; otherwise, it is assigned the value of 0.
Associated premise	BT	1 variable is used in the model. If the housing unit had an associated premise, it is assigned the value of 1; otherwise, it is assigned the value of 0.
Tram stop	DT	Distance to a tram stop (km)
Bus stop	DB	Distance to a bus stop (km)
Warta River	DW	Distance to the river (km)
Primary school and kindergartens	DS	Distance to primary school and kindergartens (km)
City centre	DCC	Distance to the centre of Poznań (km)
Urban green areas	DUGA	Distance to urban green areas (km)
Shopping centre	DSC	Distance to the shopping centre (km)

At first, the variables adopted into the model were analyzed for correlations between them. The purpose of this analysis was to check for multicollinearity between the analyzed features. Although some of the coefficients reached high values, the maximum value did not exceed 70%, which may indicate a lack of multicollinearity in the adopted database (Table 5).

Table 5. Correlation between variables.

	R1	R2	R3	SA	F1	F2	F3	BT	DT	DB	DW	DS	DCC	DUGA	DSC
R1	1000														
R2	−0.659 *	1000													
R3	−0.200 *	−0.330 *	1.000												
SA	−0.456	0.136 *	0.579 *	1.000											
F1	−0.067 *	0.023	0.081 *	0.129 *	1.000										
F2	0.052 *	−0.016	−0.065 *	−0.093 *	−0.630 *	1.000									
F3	0.030	−0.012	−0.033	−0.068 *	−0.355 *	−0.226 *	1.000								
BT	−0.164 *	0.152 *	0.011	0.018	0.015	−0.045	0.050	1.000							
DT	−0.074 *	0.005	0.127 *	0.209 *	0.169 *	−0.114 *	−0.104 *	0.003	1.000						
DB	0.007	−0.013	0.012	0.091 *	0.042	0.009	−0.089 *	−0.044	0.192 *	1.000					
DW	−0.091 *	0.036	0.098 *	0.145 *	0.129 *	−0.102 *	−0.054 *	0.080 *	0.382 *	−0.060 *	1.000				
DS	−0.068 *	−0.015	0.153 *	0.229 *	0.078 *	−0.086 *	0.008	−0.095 *	0.286 *	0.167 *	0.100 *	1.000			
DCC	−0.138 *	0.072 *	0.117 *	0.188 *	0.151 *	−0.138 *	−0.033	0.020	0.695 *	0.080 *	0.674 *	0.384 *	1.000		
DUGA	−0.022	−0.042	0.121 *	0.217 *	0.141 *	−0.090 *	−0.096 *	−0.029	0.424 *	0.118 *	0.402 *	0.275 *	0.425 *	1.000	
DSC	−0.047	−0.025	0.135 *	0.212 *	0.166 *	−0.129 *	−0.072 *	0.074 *	0.572 *	0.086 *	0.368 *	0.151 *	0.417 *	0.338 *	1

* Correlation is significant at the 0.05 level.

In the next analysis stage, evaluation of the parameters adopted for the model was performed using IBM SPSS Statistics software. The natural logarithm of housing prices was the dependent variable, while the explanatory variables were the attributes adopted for the model. The analysis was performed using two regression variants: OLS and WLS (Table 6).

Table 6. OLS and WLS estimation results.

	OLS			WLS		
	Coefficient	**Standard Error**	***p*-Value**	**Coefficient**	**Standard Error**	***p*-Value**
Constant	9.136	0.019	0.000	9.143	0.018	0.000
3 to 4 rooms	−0.220	0.011	<0.001	−0.235	0.01	<0.001
More than 4 rooms	−0.165	0.025	<0.001	−0.186	0.024	<0.001
Surface	−0.235	0.000	<0.001	−0.224	0.000	<0.001
3rd, 4th, 5th floor	0.025	0.010	0.169	0.016	0.009	0.385
From 6th floor	0.025	0.017	0.168	0.017	0.014	0.338
Associated premise	−0.049	0.010	0.007	−0.043	0.009	0.018
Tram stop	−0.104	0.000	<0.001	−0.149	0.000	<0.001
Bus stop	0.006	0.000	0.725	0.007	0.000	0.718
Warta river	0.13	0.000	<0.001	0.128	0.000	<0.001
Primary schools and kindergartens	0.023	0.000	0.249	0.01	0.000	0.592
Town centre	−0.246	0.000	<0.001	−0.234	0.000	<0.001
Parks	−0.043	0.000	0.039	−0.011	0.000	0.622
Shopping centre	−0.066	0.000	0.003	−0.125	0.000	<0.001
R^2		0.521			0.701	
N		2561			2561	

Both in OLS and WLS, most variables used in the model were statistically significant. The difference between the two models occurred only in the case of the variable related to the distance of the property from urban green areas, which turned out to be statistically insignificant in the OLS model at probability values of p less than 0.05. F1 and R1 variables were excluded from both models due to the lack of variation in the variability in the analysed database. The vast majority of parameters had the expected signs of the coefficients (except for the attribute related to the associated premises) and the predicted order of magnitude. The model estimated by WLS demonstrated higher accuracy, explained 70% of the variability, and was therefore used to evaluate particular parameters and prepare cartograms related to these characteristics: the parameters of the accessibility of tram stops and average prices.

The structural parameters of the housing unit, which from the statistical point of view had a significant influence on the value of the property, are R2, R3, and area. It is worth paying attention to the last parameter. The analysis confirmed a relationship observed during the literature review that the larger the usable floor area of a given housing unit, the lower the unit price is likely to be during a market transaction.

The attributes directly related to the location of the housing unit have a significant impact on its value. Among the attributes belonging to this group of variables are DW, DCC, and DSC. Negative signs next to the DCC and DSC variables inform about the positive influence of this factor on value. In contrast, positive signs next to the DW variable inform about the negative impact of this feature. The greater the distance to the centre of Poznań and the shopping centre, the lower was the transaction price. The results confirm the average preferences of market participants in the case of larger cities, related to everyday life in the heart of the city in a place with convenient access to highly developed service infrastructure.

Turning to the most significant characteristic related to the purpose of this study, the variable related to the accessibility of the bus stop was found to be statistically insignificant (p-value = 0.718). Bus stops have a fairly even spatial distribution within Poznań, which can result in them not playing such an essential role in the investment decisions of market

participants. In the case of the attribute related to accessibility, the variable related to the distance from a tram stop proved crucial in terms of market mechanisms. Based on the coefficient for this attribute, we may conclude that of the two comparable housing units, a significantly higher unit price (about 15% per 1 km) is achieved by a housing unit located at a shorter distance from a tram stop. The results obtained from the model partially confirm the conclusions of the preliminary spatial analysis, according to which the units belonging to Group 1 (less than 200 m to a tram stop) had the highest average unit transaction price. In the last stage of the analyses, the housing units were grouped based on the value of a parameter (distance to a stop (m) x value of the coefficient from the WLS model) against the background of the distribution of tramlines (Figure 7).

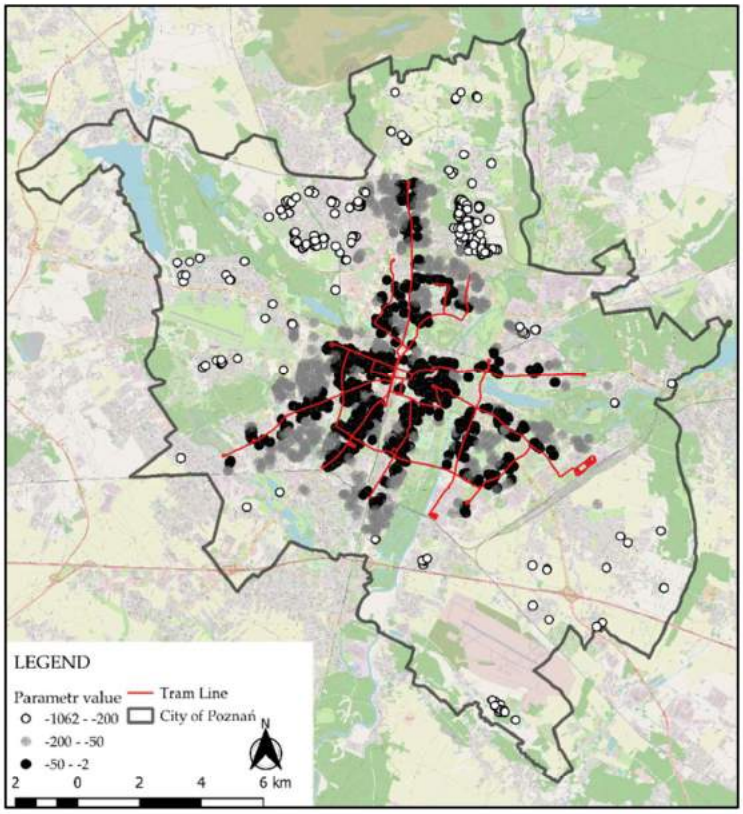


Figure 7. Classification of housing units based on a parameter that is a component of the model.

The housing units located in close proximity to tramlines had a lower value of the parameter, which directly affects their higher value. The model allowed the calculation of the average estimated values in particular districts of Poznań and, consequently, showing the distribution of average prices in a synthetic way for the entire city area (Figure 8).

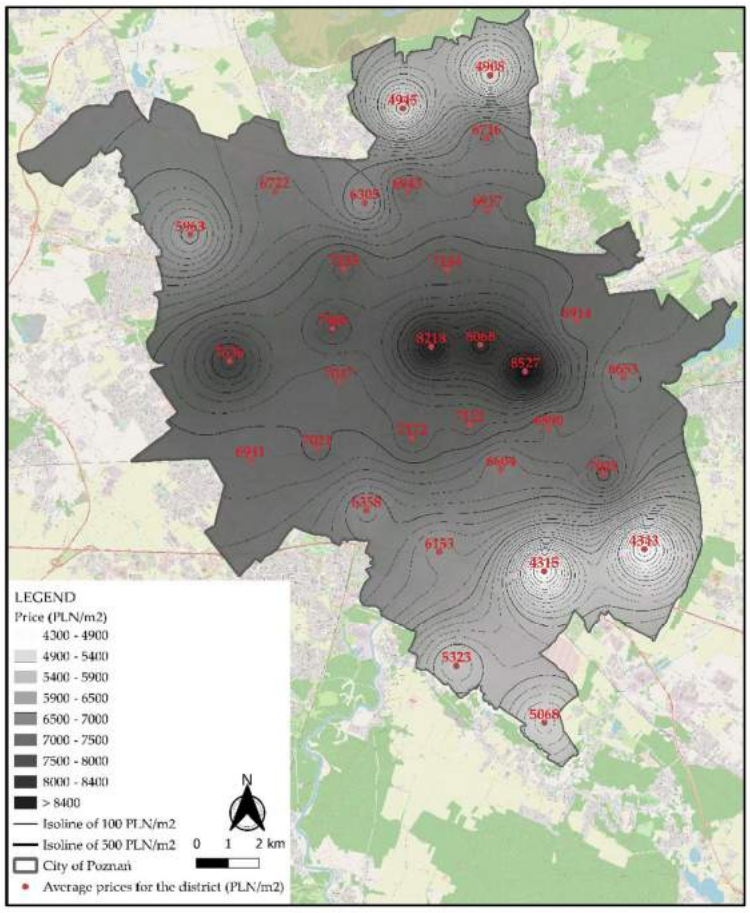


Figure 8. Distribution of average prices of housing units in Poznań.

4. Discussion

The property market shows several specific features, one of the most important of which is the imperfection, resulting in the market's low efficiency and lack of transparency. As a result of this phenomenon, the average market participants have extremely limited access to information on current market trends. On the one hand, these limitations relate to the transaction prices themselves, which are usually recorded in closed databases, and, on the other hand, to the factors which significantly determine the price. The presentation of market analyses in the form of simple thematic cartograms, presenting the analysed issue in spatial terms, may provide market participants with a lot of reliable and necessary information helpful in making investment decisions. This information can be helpful not only to buyers and sellers but also to specialised professional groups operating in the property market, i.e., property valuers, agents, and property managers. Consequently, integrating simple mathematical operations and GIS tools can yield many tangible benefits.

Our study is one of the first to analyse the impact of public transport on the value of residential property in Poland. The choice of appropriate factors for analysis is often determined by local conditions and adequate knowledge of the local market. The analyses defined the impact of the accessibility of urban public transport on the value of housing units. The use of hedonic models (OLS and WLS) further determined the influence of the structural and other types of location characteristics. The map of average prices predicted based on the WLS model synthetically aggregates the nature of the impact of location and the spatial and environmental factors on the value. However, direct comparison of the results with the existing studies may be difficult due to the local character of the property market and the difference in research scale.

The results of our analyses made it possible to select statistically significant attributes, and a great advantage of this study is its reliability because the analyses concerned data coming directly from the market. This type of analysis may have much wider applications than studies based on data from the rental market [56]. However, despite the presented advantages of our analysis, the proposed solution is not entirely without some limitations, which occur firstly in connection with the availability of data reliably and accurately describing the given housing unit. In the context of the physical characteristics of the housing units, features such as the functionality and the standard of the finish play a decisive role. Typically, however, these variables cannot be included in this type of analysis due to the lack of real opportunities to record this information, even with specialised reports. Including all relevant attributes would certainly increase the accuracy of the constructed model to a significant degree. The limitations of the presented method may be related to the nature of the property market showing substantial local variations. Therefore, the results obtained in a given area may not apply to other research subjects. It is also worth noting that the size of a given market can often determine this method. In the absence of a sufficiently large number of transactions, difficulties may arise in estimating a model that reliably describes market mechanisms.

Regarding the limitations presented, analogous studies should be conducted and gradually updated in cities or larger regions of the country. The use of comparable methods and techniques simultaneously applied in several studies would provide an opportunity to compare results and draw more meaningful conclusions. In the case of transport accessibility, enrichment of the research methodology, i.e., including factors not accepted in our study in the analysis of additional aspects, such as, among others, the Transit Opportunity Index [105,106], could significantly increase the quality of the results.

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Influence of Railroad Infrastructure on Residential Property Prices on the Example of Kórnik Municipality

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Abstract: The study's primary objective was to analyse how railroad infrastructure affects residential property prices on the example of the municipality of Kórnik. The analysis includes 737 transactions, which were concluded in 2019-2021. Input data forming the basis of the study were obtained from the District Surveying and Cartographic Documentation Centre in Poznań. The most important part of the analyses conducted was performed using the Ordinary Least Squares (OLS) method and the Geographically Weighted Regression (GWR) method. The analysis helped to identify the attributes that had the most significant impact on price. The statistical tools showed that a railroad line in the vicinity of residential properties negatively affected transaction prices. A unique role in the study is also played by spatial analyses, whose priority is to increase transparency in describing phenomena occurring within the real estate market.

Keywords: railroad infrastructure, property prices, Geographically Weighted Regression

1. Introduction

Sustainable, properly implemented transport infrastructure development brings many benefits to local communities, among which we should mention factors such as reduction of traffic congestion, levelling social differences resulting from mobility restrictions or improvement of the quality of life (Hayashi et al. 2020, Podawca &Staniszewski 2019). An important issue is also the nature of the impact of adequately operating transport on the environment, which, rationally managed, can eliminate negative aspects of its impact on the environment (Eckersten et al. 2021). On the other hand, the intensification of transport sector activities may lead to the occurrence of many negative phenomena resulting from, among

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others, pollutants emitted into the environment or noise generated (Vijay et al. 2015). As a result, factors related to transport infrastructure play an essential role in describing phenomena occurring within the real estate market, as they rank high in the hierarchy of features important to potential buyers (Liang et al. 2021).

In the context of the influence of rail transport on the real estate market, it is worth emphasising that convenient access to this type of transport can lead to an improvement in the mobility of residents, which in turn can result in greater demand for apartments located near railway halts (Yang et al. 2020). As a result of this phenomenon, with constant supply, properties of this type may reach a much higher price in market transactions. On the other hand, dwellings situated close to railroad lines, due to inconvenient noise generated by trains, may very often not be of interest to market participants, which usually results in a lower transaction price (Andersson 2010). The issue of how rail transport affects the value of the real estate is ambiguous and difficult to interpret straightforwardly, but due to its importance, it has been the subject of many research works and especially in recent years, it has clearly gained in importance (Berawi et al. 2020, Yang, Chen et al. 2020, Cohen et al. 2017, Debrezion et al. 2011).

It is worth emphasising that rail transport in Poland is essential for passenger and freight transport. Among the available means of transport, rail is in second place in terms of importance in transportation services (after road transport). The characteristics of transportation services provided by railroads make it a highly competitive means of transportation compared to other forms. A significant influence on the rating of railroads is the safety resulting from the low number of accidents in relation to, for example, car transport. In addition, convenient accessibility is crucial, being at a much higher level in relation to, for example, sea or air transport. Furthermore, rail transport is much cheaper for individual passengers than services provided on identical routes by other means of transport (Behrends 2012, Zielińska 2017).

The primary objective of this study is to identify how the proximity of a railroad line affects the transaction prices of residential units in the municipality of Kórnik. The real estate sector is an example of an imperfect market within which a property (land, buildings, premises) is a unique commodity characterised by individual features. These factors can usually be grouped into economic, physical, environmental and that conditioning the immediate surroundings (Chwiałkowski & Zydroń 2022). Comprehensive analyses related to the real estate market should consider the features of each of the mentioned groups. The price of property results from its physical conditions, such as the shape of the plot, the number of rooms or the height of the building. Nowadays, the attribute that takes into account the condition of the nearest neighbourhood is gaining in importance, including, among others, issues related to air pollution, accessibility of areas intended for tourism and recreation or proximity of airports inconvenient

for the owners of neighbouring properties (Batóg et al. 2019). Accessibility and proximity to transport infrastructure are among the priority characteristics of this group of factors (Lieske et al. 2018, Liang et al. 2021).

2. Area and material of the study

2.1. Area of the study

The urban-rural municipality of Kórnik is located in central-eastern Poland, in the central part of the Wielkopolskie Province and borders its capital city, Poznań. There are 25 surveying districts in the municipality, two of which are urban areas – Bnin and Kórnik, and the remaining ones are rural areas (Fig. 1). According to the Central Statistical Office data, the municipality is inhabited by 31,451 people (as of August 2021), and its area is 186.6 km^2. The Kórnik municipality borders the following municipalities: Poznań, Kleszczewo, Środa Wielkopolska, Zaniemyśl, Śrem, Brodnica and Mosina.



Fig. 1. Location of the study area

One railroad line no. 272 Kluczbork – Poznań Główny crosses the municipality of Kórnik. The intensity of train traffic on the line is moderate. During the week (Monday-Friday), there are, on average, 23 runs between Kórnik and Poznań, and at weekends the intensity is lower (17 runs). The line is managed by PKP Polskie Linie Kolejowe (Polish Railways), and its route is 200.90 km long and runs through two provinces: Opolskie and Wielkopolskie. It is worth noting that it is a fully electrified, double-track line with a width of 1435 mm, and the maximum speed for passenger trains on particular sections of the route is 120 km/h. In the study area, the line runs in the northern part of the municipality through the cadastral precincts: Pierzchno, Runowo, Szczodrzykowo, Borówiec, Robakowo, Gądki and Koninko (Fig. 2).

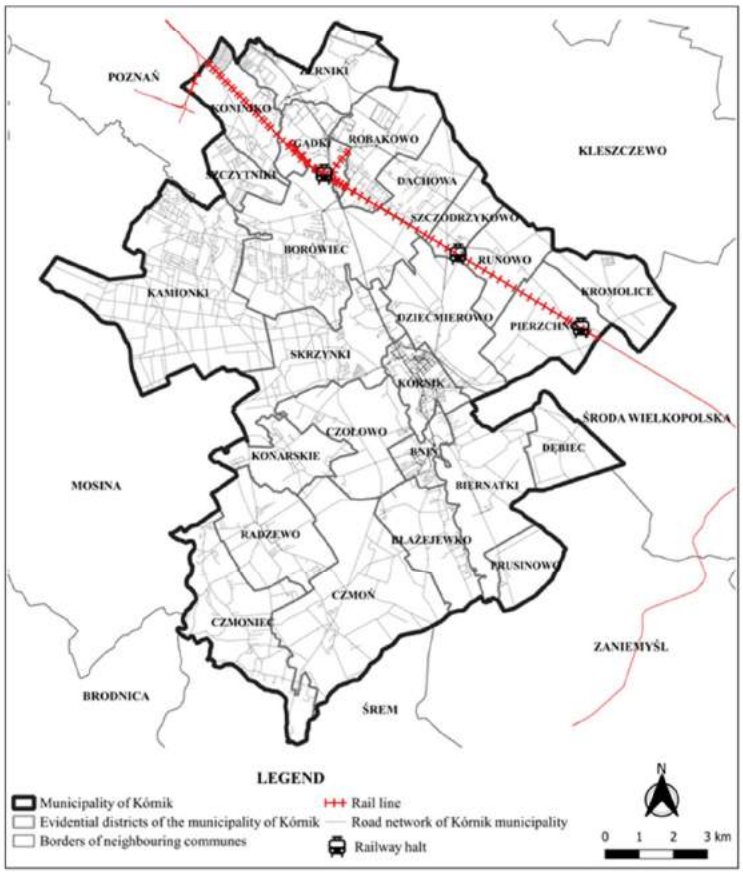
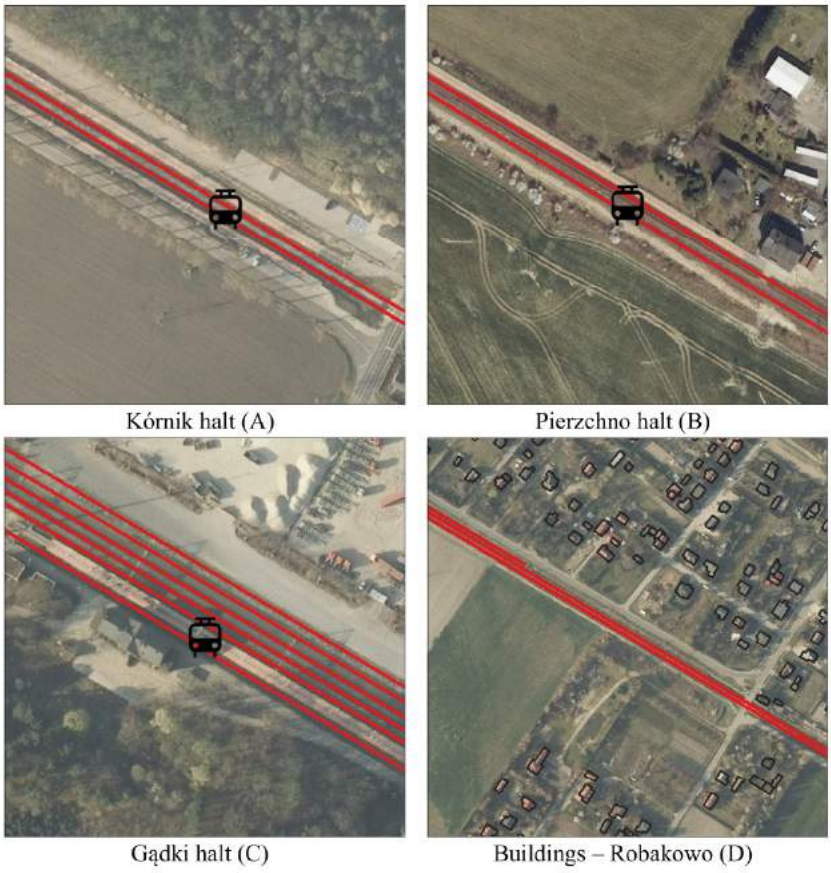


Fig. 2. Location of railroad infrastructure in Kórnik municipality

There are three halts in the Kórnik municipality: Pierzchno (passenger stop and branch station), Kórnik (passenger stop), and Gądki (station). It is worth noting that a part of the line's route runs short distances from nearby buildings, which may directly affect the local real estate market (Fig. 3).



Kórnik halt (A) Pierzchno halt (B)

Gądki halt (C) Buildings – Robakowo (D)

Fig. 3. Railway halts– Kórnik municipality

2.2. Study material

The study was conducted based on source data from the District Surveying and Cartographic Documentation Centre in Poznań. Collected data directly refer to market transactions of residential units, which were concluded in the area of Kórnik municipality in 2019-2021 – 737 transactions (Fig. 4). The information collected in the database in question formed the basis for the analyses performed to

identify how rail transport affects the prices of residential properties. The structure of the database in question makes it possible to gather information on the essential characteristics associated with each listed property. It is, first of all, necessary for defining conditions of concluding transactions information connected with price and date of transaction, area of the apartment including an area of auxiliary rooms, location of the apartment on a floor in a building and function performed by a given housing unit.

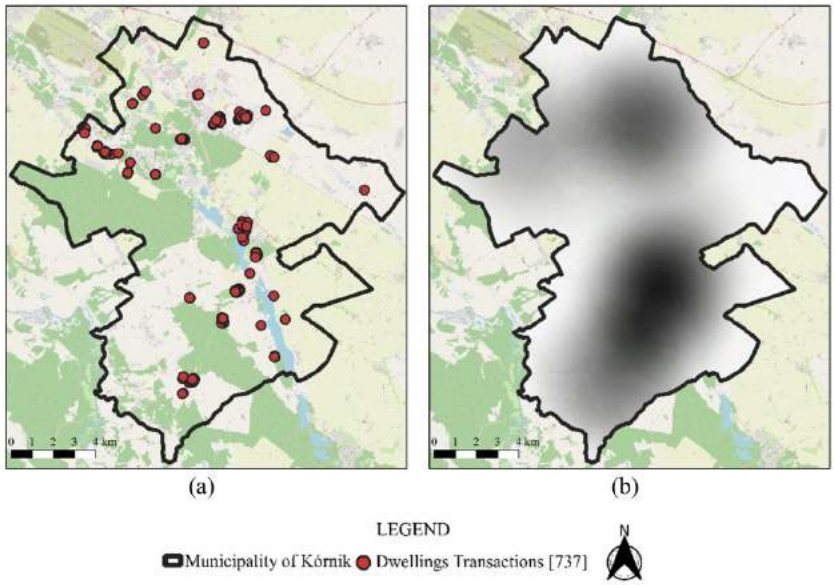


Fig. 4. (a) Location of housing units analysed. (b) Transaction density for the study area

The initial stage of analysis, carried out immediately after obtaining the source material, consisted of verification of the usefulness of the transaction data in terms of their applicability in the conducted research. As part of this process, properties whose sales transactions were carried out under non-market conditions were excluded from the database in question. In the analysed data group, this problem was most frequently related to transactions carried out for bailiff auctions and sales as part of enforcement proceedings.

The main advantage of such data recorded by public offices, such as PODGiK, is the fact that the information gathered in them comes directly from the real estate market. As a result, transactions recorded in appropriate registers based on notarial deeds constitute a reliable source of information on the mechanisms occurring within the given real estate market. The structure and characteristics of this type of data make it widely used in real estate market analyses, and,

what is extremely important, its specificity makes it much more useful than the data coming from the offer market. However, a significant drawback of this database is the lack of complementarity in terms of precise characteristics of basic attributes influencing the apartment price. Factors such as the nearest environment's condition, the building's age or the apartment's finishing standard are not included in the register, which may lead to severe errors when formulating conclusions based only on information from the database in question. Concerning the presented problem, the analyses constituting the basis for the conducted research were supplemented with information related to, among others, the characteristics of the nearest neighbourhood obtained from other types of source materials (e.g. cadastral or topographic maps).

3. Research methodology

The innovative concept related to determining the influence of selected factors on the real estate price, the foundation of which is the hedonic pricing method (HPM), originated at the beginning of the 20th century. The first documented research based on HPM method concerned the modelling of agricultural land prices and was conducted according to G.A. Hass in 1922 (Colwell & Dilmore 1999). Over time, the method has become an increasingly popular tool in various real estate market analyses. It has been applied, among others, in the characterisation of the relationship between the price of residential property and the quality of the air (Coulson 2008). In the 20th century, the theoretical scope of this method was developed in a detailed and precise manner and formulated by subsequent authors (Lancaster 1966, Rosen 1974, Maclennan 1977).

According to the most critical assumption of the HPM method, the most essential task of the estimated model is to formulate an answer to the question: how do the attributes adopted for the model influence the real estate price? The assumption that several adopted attributes define the real estate price is the fundamental essence of HPM models. The model obtained based on the statistical procedure allows for defining the values of analysed explanatory variables, such as location or the floor, which, as a result, are the components of the explained variable (price). Finally, according to the presented assumptions, the price of the apartment can be presented in the form of a standard regression equation:

$$P = f(LN, T, H, e) \tag{1}$$

where:
P – the equal price of the sold apartment,
LN – a combination of locational and neighbourhood characteristics,
T – a combination of characteristics related to transport characteristics,
H – a combination of characteristics related to the features of the dwelling,
e – standard error.

Additionally, in models of this type, the dependent variable, which is the unit price of the property, is usually defined by a standard logarithmic variable *ln(cena)*. This change is necessary because of the need to satisfy the normality requirement of the distribution of the dependent variable. Given the above proviso, the estimated model can be specified by a multiple regression equation in the following form:

$$ln(cena) = \beta_0 + \beta_1 * X_1 + \ldots + \beta_n * X_n + e \quad (2)$$

where:
β_0 – fixed element, point of intersection of the regression line,
$\beta_1, \ldots, \beta_n$ – regression coefficients,
$X_1, \ldots, X_n$ – the value of selected attributes.

This study was carried out according to a specific methodology divided into seven basic stages.

1. Selection of independent variables based on information obtained from real estate agencies.
2. Initial characteristics of the observation.
3. The final selection of the variables included in the analysis.
4. Model estimation using global regression (Ordinary Least Squares).
5. Identification of spatial autocorrelation of observations.
6. Model estimation using local regression (Geographically Weighted Regression).
7. Formulation of conclusions based on statistical analysis.

3.1. Ordinary Least Squares – Global Regression Analysis

One of the most frequently used regression techniques in real estate analysis is the Ordinary Least Squares (OLS) method. This technique is the basic method of linear modelling. According to the theoretical assumptions of this method, the relation between the explained variable and the explanatory variables can be presented with an ordinary straight line for which y values are estimated by x. According to the most essential assumption of the OLS method in the predicted model, the sum of squares of the errors of the estimated parameters should be as small as possible (Hutcheson 2019)., the global regression model can be presented in the following form, taking into account the above assumptions:

$$ln(Cena) = \beta_0 + \sum_{i=1}^{K} \beta i \, Xi + e \quad (3)$$

where:
ln(Cena) – the logarithmic unit price of the sold dwelling,
β – regression coefficient,
X – the value of the analysed characteristic,
e – standard error.

Typical statistical analysis methods, including the OLS regression technique, aim to define common relationships between the variables under study in different locations (Cao et al. 2019). However, it is essential to note that location-representative analyses cannot be performed using conventional methods, and typical OLS regression may not be sufficient to identify the determinants of real estate sales prices. An important issue is that the results obtained using the OLS method may be biased due to the heterogeneity of spatial relationships. Moreover, housing prices may be autocorrelated spatially in many cases. This feature is directly related to the standard behaviour of real estate market participants who, when putting an apartment up for sale, take into account transaction prices of similar dwelling units in the nearest neighbourhood. In addition, spatial autocorrelation may result from the fact that location and features related to the nearest neighbourhood may, in an analogous way, affect the prices of real estate in selected areas (Tomal 2020). The relationships defined in this way are confirmed in the case of the analysed data by the value of *Moran's I* test, which is statistically significant. The test value and the p-value indicate that real estate prices are spatially clustered and characterised by positive spatial autocorrelation (Table 1).

Table 1. Measures of spatial autocorrelation for the dwellings prices

Moran's Index	0.508215
Expected Index	-0.001359
Variance	0.000457
z-score	23.825619
p-value	0.000000

3.2. Geographically Weighted Regression – Local Regression Analysis

The geographically weighted regression (GWR) method was proposed in 1996 to address the problem arising from spatial dependence effects (Brunsdon et al. 1996). The GWR technique can be interpreted as an extension of the OLS global regression method with the proviso that GWR allows local parameter estimation based on samples within the bandwidth of a local location. As a result, the GWR model can be represented by the formula:

$$ln(Cena) = \beta_0 (x_i, y_i) + \sum_{i=1}^{K} \beta i(xi, yi)\, Xi + e \quad (4)$$

where:
x_i, y_i – geographical coordinates of i^{th} point,
$\beta_0(x_i, y_i)$ – site-specific intersection point,
$\beta_i(x_i, y_i)$ – the location-specific coefficient for point i,
X_i – variable related to $\beta i(xi, yi)$,
K – number of estimated parameters,
e – standard error.

From the presented equations related to OLS and GWR regressions, the global model can be interpreted as a specific case of a local model. The main difference is the assumption that in the global model, the parameters are taken as constant, while the model based on GWR recognises the spatial variation of these parameters. A significant step in GWR regression execution is equation calibration, during which an assumption is made that data observed near the location of a given point have a more significant influence on the estimation of specific coefficients concerning observations located at a longer distance. The parameters of the estimated model using the GWR technique are estimated locally using the weighted least squares method, resulting in closer data being more significant concerning further observations (Fotheringham et al. 2003, Lin & Wen 2011). In conclusion, it can be said that the fundamental difference between OLS and GWR techniques is that the coefficients in the global model are fixed, whereas the coefficients in the local model are variable and depend on the location.

4. Results

In the first research stage, the independent variables accepted for analysis based on information obtained from real estate agencies were subjected to preliminary analysis. A prevalent problem in analyses of this type is the occurrence of multicollinearity between the adopted characteristics and skewness, which is a measure of the asymmetry of the analysed observations. In this study, attributes with a skewness value more significant than three were logarithmically transformed (Yang 2014). Next, OLS regression was estimated using which VIF (Variance Inflation Factor) values were calculated for the analysed attributes. Attributes with a VIF value greater than 7.5 were excluded from the final part of the analysis (Table 2).

In the initial stage, basic descriptive statistics such as mean, standard deviation, median, maximum and minimum values were defined for the general characterisation of the observations. Then, these statistics were formulated for both the dependent and explanatory variables (Table 3).

Table 2. Characteristics of qualitative and quantitative variables applied in the model

Feature	Symbol	Feature Description	Form
Price	P	Housing price (PLN/m^2)	Logarithmic
Rooms	NR	Number of rooms	Standard
Water	DW	Distance to surface water (m)	Standard
Shop	DS	Distance to stores (m)	Variable deleted due to high VIF value
Forest	DF	Distance to a forest (m)	Standard
Center	DC	Distance to the centre of the Kórnik municipality (m)	Variable deleted due to high VIF value
School	DS	Distance to schools (m)	Standard
Poznań	DP	Distance to Poznań (m)	Variable deleted due to high VIF value
Park	DPark	Distance to parks (m)	Variable deleted due to high VIF value
Roads	DR	Distance to nearest main or secondary road (m)	Standard
Rail	DRail	Distance to the railroad (m)	Standard
Busstop	DBS	Distance to a bus stop (m)	Standard
Surface	SA	Apartment surface (m^2)	Logarithmic
Basement	BT	Accessible amenity space (0 – no access,1 – access)	Standard
Age of building	AoB	Building age (0 – building over 5 years, 1 – building less than 5 years)	Standard

Table 3. Descriptive statistics of dependent and independent variables

	Mean	Median	Standard deviation	Max	Min
P (PLN/m^2)	5493.31	5486.25	484.39	6438.17	4447.07
NR (number of rooms)	2.56	3.00	1.34	6.00	1.00
DW (m)	464.84	483.82	247.56	953.54	23.66
DS (m)	1660.81	689.53	1821.77	6069.35	13.05
DF (m)	438.78	460.01	322.85	2329.12	0.00
DC (m)	4938.38	5787.10	2469.75	9589.55	63.08
DS (m)	593.98	420.98	535.45	4597.37	7.14

Table 3. cont.

	Mean	Median	Standard deviation	Max	Min
DP (m)	7332.98	8812.95	3897.31	13093.26	653.32
DPark (m)	2682.09	2025.16	1882.03	6869.76	29.04
DR (m)	350.00	255.02	315.57	1109.63	4.99
DRail (m)	5045.59	4083.85	3579.19	11599.06	88.22
DBS (m)	499.69	357.78	442.90	2094.62	1.45
SA (m^2)	190.56	70.89	2318.81	44666.00	14.49
BT (0 or 1)	0.28	0.00	0.45	1.00	0.00
AoB (0 or 1)	0.03	0.00	0.17	1.00	0.00

Based on the results obtained from the OLS global regression model, it can be concluded that most of the variables are statistically significant at p-value = 1%. The variables that are not statistically significant are NR, DW, DS and DR. The obtained model explains slightly more than 55% of the variability of the observed phenomenon. Generally, it should be remembered that negative values of coefficients (e.g. for the feature distance from surface waters – DW) in the case of attributes defined by distance measurements indicate a positive influence of a given feature on the price of analysed properties. Based on the coefficient for the attribute that is the most important from the point of view of the defined objective of the study, *DRail (0.000053)*, we may conclude that the prices of properties located at a closer distance from the railroad line are relatively more minor concerning the prices of comparable properties located at a greater distance to this attribute (Tab. 4). In percentage terms, however, the price difference due to the change in the distance from the railroad line is small and amounts to 0.5% (the value of the *DRail* attribute changes by 0.5% with a change of 1.0 m).

Table 4. Summary of ordinary least squares (OLS) regression results

	Coefficient	Standard error	T-value	P-value	VIF
Intercept	8.678457	0.026777	324.101372	0.000000*	–
NR	- 0.000582	0.001840	-0.316334	0.751851	1.256349
DW	-0.000011	0.000012	-0.919074	0.358348	1.712105
DF	0.000024	0.000008	2.909802	0.003734*	1.400698
DS	-0.000005	0.000005	-1.150948	0.250130	1.231048
DR	-0.000002	0.000009	-0.227415	0.820165	1.823361
DRail	0.000053	0.000010	5.555327	0.000000*	3.652521

Table 4. cont.

	Coefficient	Standard error	T-value	P-value	VIF
DBS	-0.000009	0.000001	-5.911264	0.000000*	5.865754
SA	-0.020480	0.005904	-3.468595	0.000569*	1.175111
BT	0.115040	0.006268	18.354615	0.000000*	1.616779
AoB	0.066150	0.014016	4.719699	0.000004*	1.118002
Number of Observations				737	
Multiple R-Squared				0.5631	
Adjusted R-Squared				0.5571	
AICc				-2045.25	

* indicates $p < 0.01$

The results obtained from using geographically weighted regression (GWR) indicate a slight difference in the global regression (OLS) results. For the analysed research group in the case of GWR regression, the value of adjusted R-Squared is 0.5724 (OLS: 0.5571), and the value of AICc is equal to -2068.15 (OLS: -2045.25) (Table 5). Based on these values, we can conclude that GWR for the analysed data group is characterised by minimally more efficient modelling quality.

The indisputable advantage of GWR regression over OLS regression is the ability to estimate variable coefficients both at the location of the observations themselves and at any other arbitrary location in the study area, even when no data are recorded there. The local coefficients of the *DRail* trait estimated for the properties analysed range from 0.000020 to 0.000054. Overall, the results confirm the negative impact of noise on housing prices. However, it is worth noting that the nature of noise pollution in different areas cannot be unambiguous, as the results of three research facilities located in Great Britain confirm (Blanco & Flindell 2011). It is worth noting that a different way of noise impact may occur mainly in the case of larger cities, where, despite the noise generated by transport infrastructure, the prices of dwellings located near railway stations or railway lines may be higher due to more convenient transport accessibility, which is confirmed by the results obtained, among others, in Hamburg (Brandt & Maennig 2012). Generally, with a few exceptions, observations located in the northern part of the community and those located near the railroad route had smaller coefficient values for *DRail* (Fig. 5).

Table 5. Summary of Geographically Weighted Regression (GWR) regression results – regression coefficients

Variable	Mean	SD	Min	Max	Median	Mean Standard error
Intercept	8.588652	0.017314	8.566629	8.621381	8.582384	0.015376
NR	-0.000685	0.001050	-0.003259	0.000577	-0.000830	0.002147
DW	-0.000015	0.000028	-0.000053	0.000024	-0.000010	0.000014
DF	0.000017	0.000003	0.000009	0.000020	0.000018	0.000009
DS	-0.000011	0.000012	-0.000026	0.000009	-0.000016	0.000006
DR	0.000009	0.000008	-0.000005	0.000025	0.000014	0.000011
DRail	0.000044	0.000008	0.000020	0.000054	0.000046	0.000001
DBS	-0.000007	0.000001	-0.000008	-0.000005	-0.000007	0.000002
SA	0.000001	0.000000	0.000000	0.000001	0.000001	0.000011
BT	0.119689	0.013177	0.096406	0.139174	0.120963	0.007405
AoB	0.067219	0.004199	0.057741	0.072577	0.068634	0.017513
Number of Observations				737		
Multiple R-Squared				0.5841		
Adjusted R-Squared				0.5724		
AICc				-2068.15		

GWR analysis also allows us to determine a continuous surface within the examined area for which the values of particular coefficients can be estimated, as confirmed, i.a., by a study carried out in Olsztyn, a city in north-eastern Poland (Cellmer 2011). As a result of this phenomenon, it is possible to create complex maps that can provide valuable information for making critical decisions related to the development of housing infrastructure in a given region. In the next part of the paper, a thematic map was prepared, which includes local coefficients for *Drail* feature for the whole area, estimated based on GWR regression analysis results (Fig. 6).

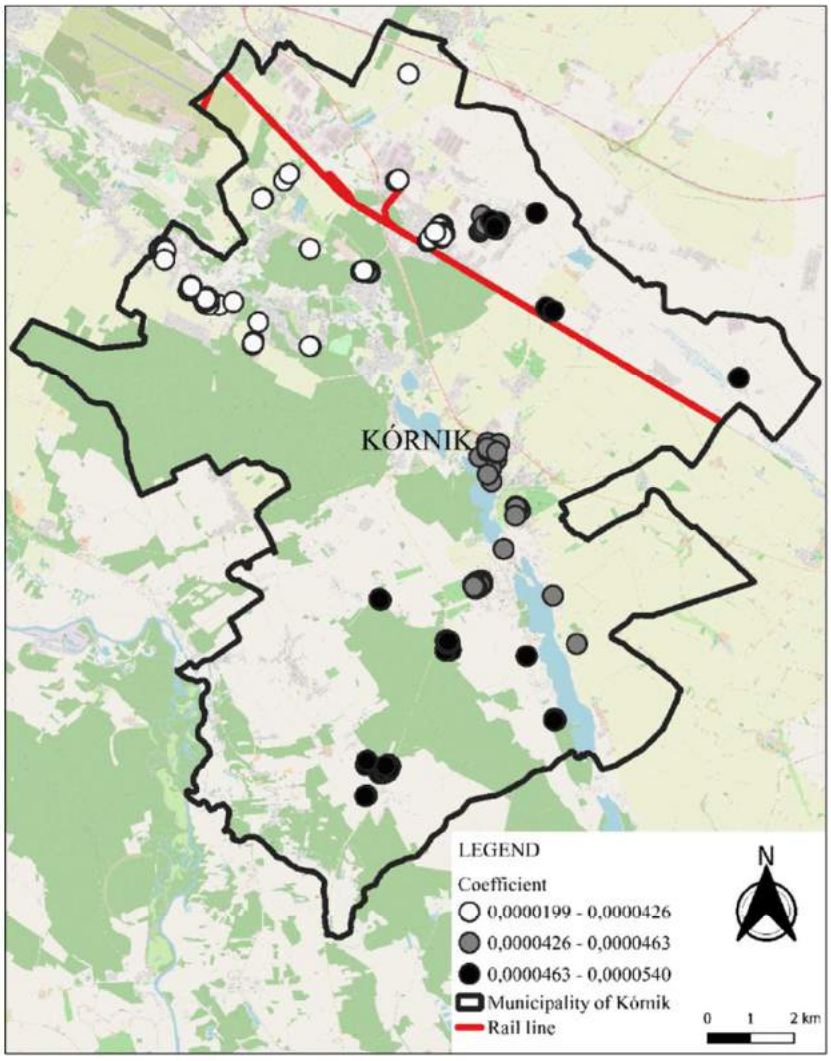


Fig. 5. Local coefficient estimates for Drail

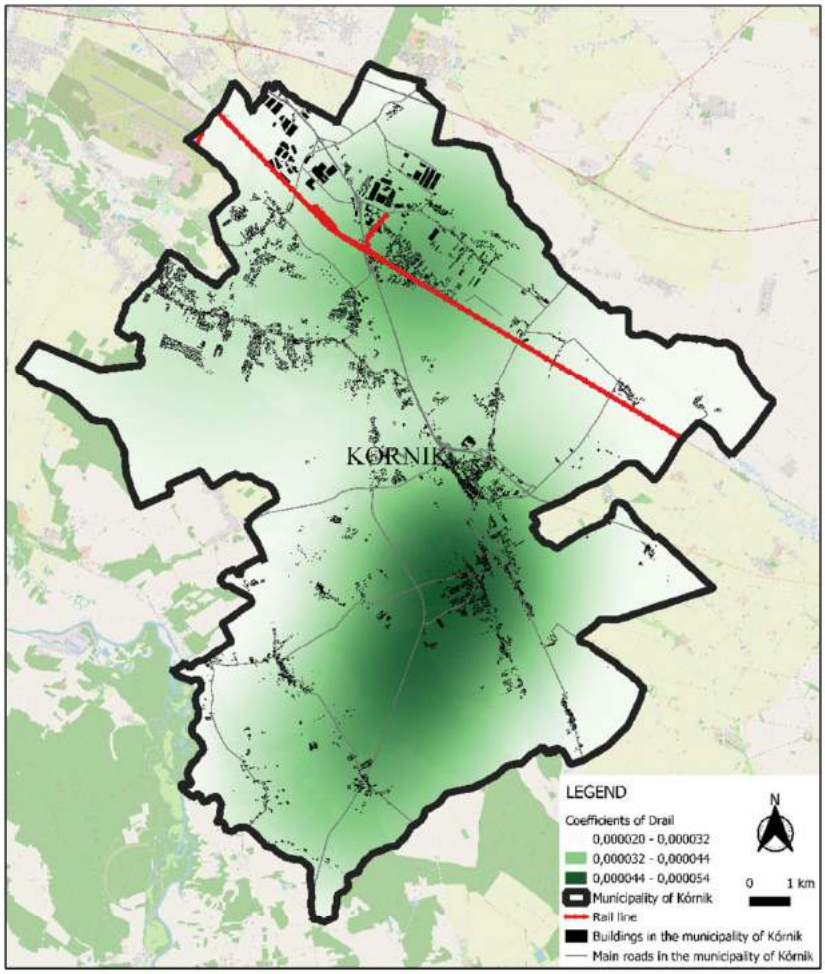


Fig. 6. Maps of local coefficient estimates of explanatory variables DRail

Within the study area, the effects of the feature under investigation are different and comparable to the effects of aircraft noise in the Polish capital Warsaw (Cellmer et al. 2019). The spatial distribution pattern of the *Drail* feature within the Kórnik municipality indicates a more substantial negative impact of this attribute on housing prices (lower coefficient value) in the municipality's northern part, situated close to the railroad line. For the central part of the gmina, where e.g. the town of Kórnik is located, the value of the coefficient is considerably

higher, which proves that an increase in the distance from the railroad line to the other areas of the Kórnik municipality has a much stronger effect on the increase of residential property prices.

5. Discussion of the results

In our study, we applied the HPM method using OLS and GWR techniques. The study's most important objective was to examine how the proximity of a railroad line affects the prices of residential properties in the municipality of Kórnik, located within the boundaries of the Poznań district. Due to its location, issues related to the transport sector are of particular importance for the municipality of Kórnik from the point of view of both socio-economic development and increasing accessibility to efficient public transport. The total number of properties accepted for the analysis included 737 transactions, which were concluded between 2019 and 2021.

It is worth emphasising that the observations used in this study have the character of spatial data, which is extremely important in the context of the characteristics of issues related to the location defined, among others, by analysing spatial autocorrelation (Getis 2007). This problem is often not considered in preparing analyses, which can lead to an incorrect definition of local spatial dependencies. Spatial regression models (e.g. GWR), in comparison to standard regressions (OLS) take into account local spatial relationships, which consequently results in a much higher level of detail of results at the local level (Sheehan et al. 2013). Our findings directly confirm that the DRail feature coefficients are differentiated and non-uniform for the whole municipality area. Despite minor differences, it is worth noting that the analysed case study GWR model, compared to the OLS model, was characterised by higher accuracy, evidenced by the value of adjusted R2 and AICc. The obtained results confirm that rail transport can influence the mechanisms within the real estate market within certain limits. The results formulated in this study may indicate and set perspectives for developing public transport services and directions for housing intensification. It is also vital to emphasise that the conclusions resulting from this analysis may be applied not only to the commune of Kórnik itself but also to other administrative units comparable in socio-economic terms.

Despite the presented advantages of this study, it has, obviously, some limitations. Firstly, the analysis could be performed more comprehensively by collecting more precise information on the analysed properties. The inclusion in the study of additional characteristics related primarily to physical factors such as, among others, the standard of housing or the use of other types of methods could lead to a better fit of the built model (Manasa et al. 2020). Additionally, comparing the results with previous work from a comparable area and the determination of time series could enrich the obtained results with information about changes

over time, which would contribute directly to the determination of changes in housing preferences among the population. In this context, the study is critical and constitutes a kind of reference point for future analyses.

6. Conclusions

1. The results we obtained for the analysed area show that the presence of a railroad line negatively affects the prices of properties located in the immediate vicinity, most likely due to the emission of excessive communication noise.
2. Due to spatial autocorrelation, the Geographically Weighted Regression (GWR) method has a legitimate application in real estate research.
3. The method presented in the study may have some limitations due to, among other things, how the selected attributes interact with each other. For example, the way the attributes interact may be different due to the type and spatial extent of the real estate market. In addition, the impact of factors on price may vary over time due to a particular market's social and economic conditions.

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Assessing the Impact of Selected Attributes on Dwelling Prices Using Ordinary Least Squares Regression and Geographically Weighted Regression: A Case Study in Poznań, Poland

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Abstract: The price of dwellings is determined by a number of attributes among which location factors are usually the most important. Comprehensive analyses of the real estate market should take into account a broad spectrum of attributes including economic factors, physical, neighborhood and environment characteristics. The primary objective of the study was to answer the question of what determinants affect transaction prices within the housing market in Poznań. The analysis was performed on the basis of source data obtained from the Board of Geodesy and Urban Cadastre GEOPOZ in Poznań. In our study, we used two research regression methods: ordinary least squares and geographically weighted regression. The estimated models made it possible to formulate specific conclusions related to the identification of local determinants of housing prices in the Poznań housing market. The results of the study confirmed that the use of the proposed techniques makes it possible to identify attributes relevant to the local market, and, moreover, the use of spatial analysis leads to an increase in the quality of the description of the characteristics of the analyzed phenomenon. Finally, the results obtained indicate the diversity of the analyzed market and highlight its ambiguity and complexity.

Keywords: property market; hedonic price model; dwelling prices; regression analysis; locational indicators

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1. Introduction

1.1. Market of Dwellings

The price of property depends on a number of factors, which, in principle, can be divided into physical, locational, environmental and economic characteristics [1–3]. A special role within the market of dwellings is played by locational factors, which usually rank highly in the hierarchy of market participants [4,5]. Location is an important attribute primarily because it is not possible to modify it, unlike most other attributes, e.g., the standard of finish can be upgraded by performing a major renovation. The way in which the location attributes interact with the characteristics of the immediate neighborhood especially in recent years has been one of the key elements of research related to the characteristics of the property market [6–9].

At the same time, it should be emphasized that for many potential buyers, other attributes such as the situation of the apartment on the floor can often be much more important than the location of the apartment. Market participants increasingly pay attention to mundane issues such as the insolation of the apartment. The assumption that only location affects prices is incorrect. If this concept were true then two exemplary apartment properties located in one building would reach an identical price during the transaction. Practice, on the other hand, proves that even when these apartments have the same area,

the transaction price can be divergent due to differences in other attributes. In addition, it should be remembered that one of the basic characteristics of a property regardless of type is heterogeneity, and as a result, among other things, attributes that are important for one type of property may be of marginal importance in the case of a property of a different type. Given these assumptions, comprehensive property market analyses should absolutely take into account the attributes belonging to each of the four defined groups. A review of the literature on the subject, carried out at an initial stage, made it possible to distinguish a number of important attributes within the property market belonging to each of the distinguished groups (Table 1).

Table 1. Attribute categories based on the literature.

Category	Variable	Author
Physical characteristics of the apartment	Area of the apartment	Čeh et al. [10]
	Number of rooms	Escobedo et al. [11]
	Age of the building	Wu et al. [12]
	Type of housing unit	Park et al. [13]
	Availability of parking/garage	Ko et al. [14]
	Floor location	Szczepańska et al. [15]
	Building construction	Trojanek et al. [16]
	Form of ownership	Marano and Tajani [17]
	Basement availability	Ottensmann et al. [18]
	Standard of finishing	Tomal [19]
	Energy efficiency	Zancanella et al. [20]
Characteristics of neighborhood	Distance to city center	Payton et al. [21]
	Distance to schools	Sah et al. [22]
	Availability of public transport	Cordera et al. [23]
	Distance to stores	Heyman et al. [24]
	Distance to recreational areas	Tyrväinen [25]
	Nuisance neighborhoods (airport, etc.)	Kopsch [26]
	Distance to industrial zones	Wittowsky et al. [27]
Characteristics of environment	Distance to lakes	Sander and Haight [28]
	Distance to green areas, parks	Łaszkiewicz et al. [29]
	Distance to legally protected areas	Pearson et al. [30]
	Air pollution	Chen and Chen [31]
	Distance to other valuable natural areas (e.g., mountains)	Xiao et al. [32]
Characteristics of economic conditions	Volume of taxes	Munro and Tolley [33]
	Demographic structure	Lai [34]
	Employment opportunities	Ding et al. [35]
	Prospects of economic development	Perdomo [36]
	Value of income generated	Feng [37]
	Degree of development of enterprises	Md and Sheikh [38]
	Occurrence of planning barriers	Hussain et al. [39]
	Value of macroeconomic factors	Li and Chu [40]

1.2. Poland's Property Market and Macroeconomic Conditions

The property market is one of the most important sectors of the economy, and the share of outlays on housing, understood by both maintenance of the existing stock and new investments, usually accounts for 8–20% of Poland's GDP [41]. As a result of this relationship, property market processes are inextricably linked to the common conditions prevailing in the country's economy. As a result, economic factors should be an integral and key component of research related to property management [42–45]. Taking this into account, the introductory part of the work consists of a brief characterization of the macroeconomic situation over the past few years in Poland.

As part of the initial characterization of the database in question, which is the foundation of this work (dwellings transactions in 2019–2022 concluded within the boundaries of the city of Poznań), it should be noted that over the analyzed period of time, the macroeconomic conditions directly affecting the property market underwent significant changes. A special role in this process was played by the Monetary Policy Council, which is the decision-making body of the National Bank of Poland, which from the beginning of 2020 took a number of measures to mitigate the negative economic effects of the coronavirus pandemic. In order to intensify the level of investment and increase consumption, the aforementioned body has repeatedly decided to reduce the interest rates of the National Bank of Poland [46,47]. As a result, at the end of May 2020, interest rates reached record low levels not seen in the 21st century (reference rate—0.10, deposit rate—0.00, lombard rate—0.50, rediscount rate for promissory notes—0.11, discount rate for promissory notes—0.12). The aforementioned indexes were maintained at the indicated levels until the beginning of October 2021, when, due to the problem of drastic price increases gaining importance, the Monetary Policy Council decided to raise interest rates repeatedly. As a result, at the end of the analyzed time period, interest rates reached the following values: reference rate—3.50, deposit rate—3.00, lombard rate—4.00, rediscount rate for promissory notes—3.55, discount rate for promissory notes—3.60 [48]. In the following months, these values continued to be increased by subsequent decisions of the decision-making body of the National Bank of Poland.

Decisions related to interest rates directly affect the situation in the property market (especially housing); an increase in NBP interest rates leads to an increase in both the interest rate on the loan itself and interest, which automatically leads to an increase in loan installments. As a consequence, the number of people/entities that can apply for a mortgage is clearly decreasing due to the tightening of criteria related to the granting of credit, i.e., creditworthiness [49–52]. A special social group that may suffer the consequences of the described phenomenon may be the younger generations, who, as a result of a significant tightening of monetary policy, may not be able to purchase their own housing [53]. This phenomenon can ultimately lead to a significant increase in the level of poverty; very often it is even one of the main factors determining it [54]. In addition, it should be taken into account that this phenomenon can be compounded by the increased cost of housing, defined, for example, by the cost of electric energy, the prices of which have clearly increased in Central and Western European countries due to the pandemic but also the ongoing war [55]. As a result, it is extremely difficult not only to buy an apartment, but also to maintain it. Very often, it becomes more profitable and attractive to rent an apartment instead of buying it. A certain solution in such a situation for the cited social group may be to increase the supply of housing by, for example, intensifying housing investment within the non-commercial third housing sector (THS), the primary purpose of which being to improve the living conditions of households with low or medium levels of financial wealth [56]. At the same time, it should also be borne in mind that direct government intervention in the housing market, defined, among other things, by the introduction of temporary tax breaks for buyers of houses/apartments, can have a negative effect. In spite of the fact that such actions usually in the first stage lead to the revival of the market by increasing demand and raising prices, as a consequence they can have a clear impact on reducing the welfare of societies [57]. Taking this into account, it should be borne in mind that any centrally planned government interventions should be well thought out and well planned.

Based on NBP reports, it should be emphasized that in the case of apartments, the share of transactions financed by credit has been gaining importance in recent years and has become more popular in relation to transactions financed by own funds. In extreme cases, the purchase of as much as 68% (Q2 2020) and 50% (Q3 2021) of apartments in Poland was financed with credit [58]. As a consequence of the tightening of the criteria for granting mortgages, the demand in the housing market may significantly decrease which, if the supply remains constant, may lead to a marked decrease in transaction prices [59,60].

On a national scale, additionally taking into account the processes associated with the tendency to overvalue property prices [61,62], after several years of price increases in Poland, there is a real possibility of a significant decline in housing prices, while taking into account the differences in the potential of regional markets related to local regulations and socio-economic conditions [63–66]. The property market, due to its characteristics, reacts to the events described above with some delay. Consequently, although their impact on the processes taking place within them is undeniable, their effects will be visible in the long term.

With reference to the conditions outlined above, this study attempts to answer the question of what types of attributes significantly affect the prices of residential real estate within the analyzed market. The primary objective of the study was to identify the factors that are most relevant to market participants at a time of changing macroeconomic conditions. The analysis carried out is further aimed at verifying whether there is spatial autocorrelation of transaction prices for the analyzed dataset, as well as comparing the built models in terms of accuracy in describing the studied phenomenon.

2. Materials and Methods

2.1. Study Site and Data

The study in question was carried out within the administrative boundaries of the city of Poznań, which has the status of capital of the Wielkopolska Voivodeship and plays a key role in the social and economic development of neighboring administrative units. The city is located in the western part of Poland, while within the Wielkopolska Voivodeship it is situated in its central part (latitude of the city—northern hemisphere, longitude of the city—eastern hemisphere). The total area of the city equals 262 km^2. Within the boundaries of Poznań there are 40 cadastral precincts (districts); the largest covers an area of 13.78 km^2 (Kobylepole), while by far the smallest is the Daszewice—0.06 km^2 (Figure 1).

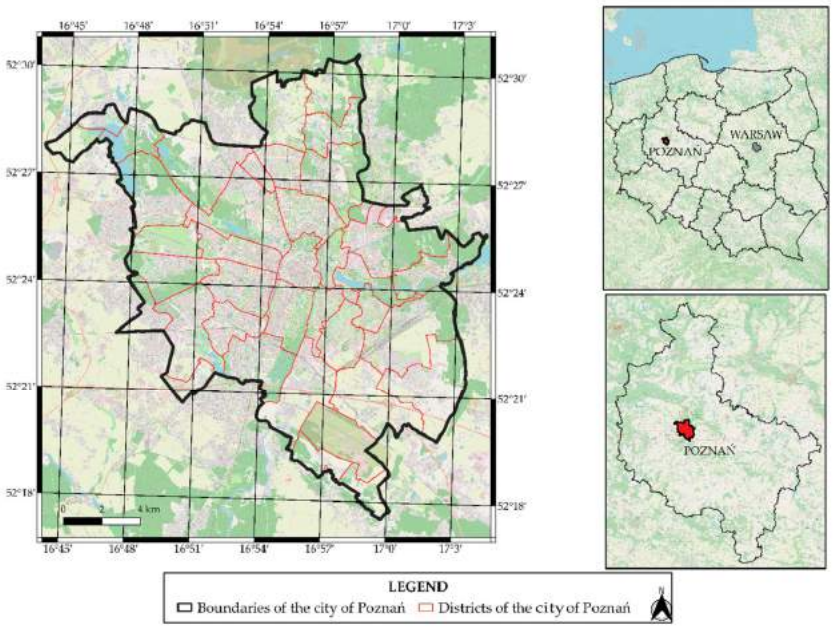


Figure 1. Location of the research facility—Poznań.

According to the Central Statistical Office, the city's population in 2021 was 529,410. A clear majority in the total population were women (about 53%, i.e., 282,307), while men made up a minority of the city's population (nearly 47%, i.e., 247,103). People who are of working age constitute a clear majority in the demographic structure of the population (nearly 60%); 25% are post-production age, and the remaining 15% of the city's population is made up of people of pre-production age (under 15). A detailed analysis of the state of the population over the past few years within Poznań makes it possible to note, first of all, a non-significant but fairly systematic reduction in the total population (2019—534,813 people, 2020—532,048 people) which may be partly related to the COVID-19 pandemic. According to the Central Statistical Office, more than 506,000 people died in Poland in 2021 (the most since World War II); in 2020, this figure was about 477,000 Poles which, compared to 2019 (409 thousand), demonstrates the extremely significant way in which demographics have been affected by both the pandemic itself and the not-always-effective measures taken to limit its spread.

The analysis underpinning this study was carried out on the basis of source data obtained from the Board of Geodesy and Urban Cadastre GEOPOZ in Poznań. The most relevant component of the data in question is the transactions of housing units that were concluded within the city boundaries of Poznań from the beginning of January 2019 to the beginning of March 2022. The key task of the analysis was to identify attributes that significantly affect prices in a changing economic environment. The selected dataset ultimately consisted of 6611 residential real estate transactions concluded in 2019–2022. The vast majority of transactions were concluded in the central part of the city (districts: Łazarz, Jeżyce and Old Town) and partially in the northern part of Poznań (districts: Piątkowo and Naramowice) (Figure 2).

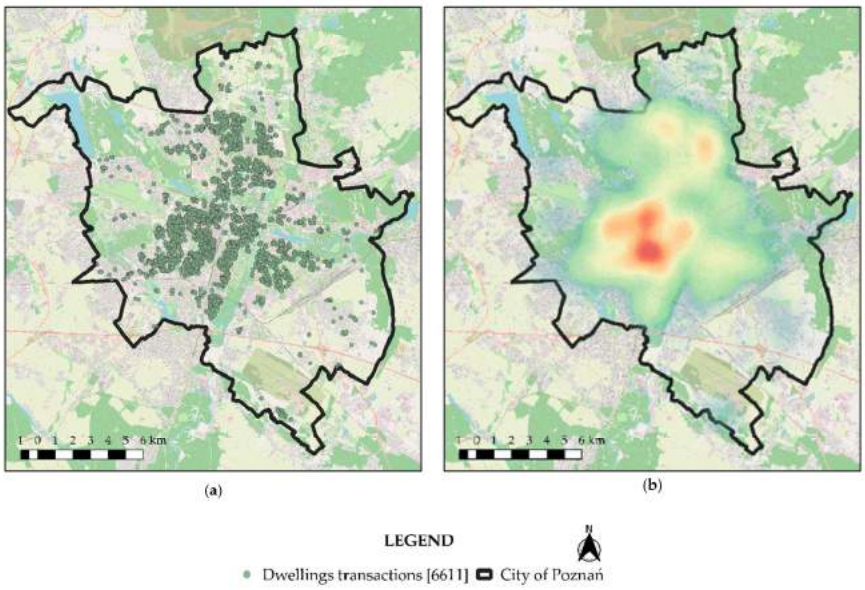


Figure 2. (**a**) Location of housing units analyzed. (**b**) Transaction density within the study area.

The basic data recorded in the subject database include the most relevant information related to each transaction, i.e., the transaction price, the date of the transaction, the area of the apartment, the area of auxiliary premises and information about the floor on which the

apartment is located in the building. The main advantage of this type of data is its source. Due to the fact that these data are derived from notarial deeds, they constitute a reliable and credible database, which is indispensable, among other things, during the process of monitoring the current situation in the real estate market and the characteristics of the mechanisms occurring within a given market. Despite the numerous advantages of this type of data, it is necessary to bear in mind certain problems associated primarily with the lack of complementarity in terms of the characteristics of the property according to the basic features that can directly determine the transaction price. An analysis that aims to identify attributes of key importance without taking into account characteristics such as, among others, the closest neighborhood, the technical condition of the building or the standard of finish (undefined in the surveyed register) may be unjustified and presumably may result in erroneous conclusions. In order to eliminate the above problem, the basic source data were additionally supplemented with features related to the locational characteristics of the analyzed properties.

The average unit prices of the collected transactions were in the range of PLN 3000 per sqm to PLN 16,000 per sqm in the extreme case. The lowest average prices were recorded in districts located far from the city center, such as Głuszyna, Spławie and Kotowo. On the other hand, the highest average prices, often exceeding PLN 10,000 per sqm, were recorded in the central part of the city in districts such as Jeżyce, Old Town and Wilda. Based on the collected transactions and their locations, a map of interpolated average prices in places where it was possible to determine them was prepared (Figure 3).

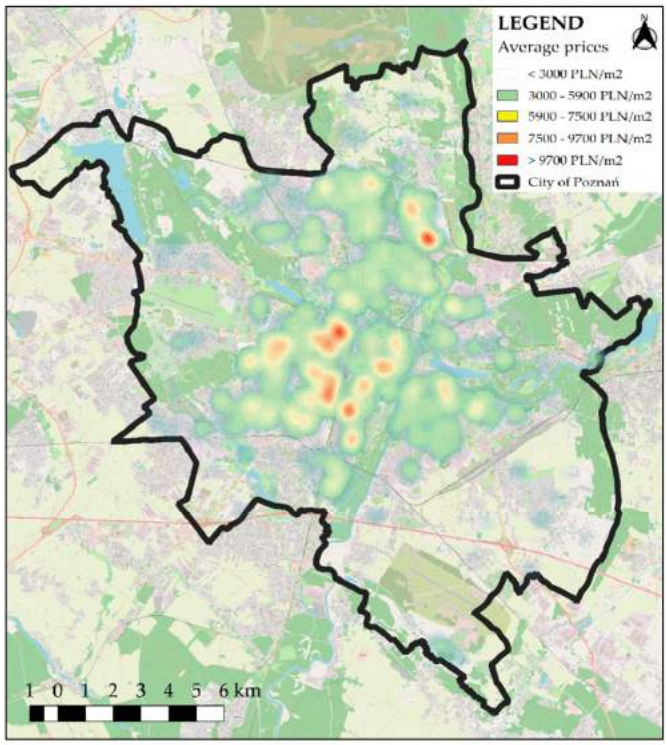


Figure 3. Interpolation of housing prices within the study area (kernel density estimation).

2.2. Regression Analysis

The hedonic regression method (HPM) is the foundation of research related to the process of analyzing how selected attributes affect the price of property, and the first studies related to it date back to the early 20th century. The first pioneering analysis performed using HPM involved the modeling of agricultural land prices [67]. Subsequently, the method served as a useful tool, among other things, in the process of characterizing the relationship occurring between the transaction price of dwellings and the level of air pollution [68]. In the second half of the 20th century, the theoretical framework of the HPM method was developed in a thorough and precise way by subsequent authors [69–71].

According to the basic assumption of the method in question, the price of property is determined by a number of attributes adopted into the model, a concept that is the fundamental essence of HPM models. Given this assumption, the key task of the estimated model is to answer the following question: to what extent do the independent variables included in the model affect the price of property? As a result of the applied statistical procedure, the obtained model allows for the defining of the values of the analyzed attributes, which are further components of the dependent variable, i.e., price. Finally, according to the above assumptions, the price of an apartment (or any other property) can be presented in the form of a standard regression equation:

$$P = f(LN,\ H, \beta, e) \tag{1}$$

where:

P—equal price of the apartment sold,

LN—a combination of locational and immediate neighborhood-related features,

H—a combination of features related to the physical characteristics of the apartment,

β—a combination of features related to the characteristics of local planning and social and economic conditions,

e—standard error.

After taking the appropriate independent variables into consideration, the estimated model of the dependent variable can be represented by a multivariate regression equation in the following form:

$$P = \beta_0 + \beta_1 \times X_1 + \ldots + \beta_n \times X_n + e \tag{2}$$

where:

$\beta_0, \beta_1 \ldots, \beta_n$—regression coefficients.

$X_1, \ldots, X_n$—values of the analyzed characteristic.

2.2.1. Ordinary Least Squares

The ordinary least squares (OLS) technique is one of the most widely used methods in regression analyses related to the definition of mechanisms occurring within the property market. OLS is a basic linear modeling method, and according to the fundamental theoretical assumptions of this method, the relationship between the dependent variable and the independent variables can be defined by a simple straight line for which the values of y (price) are estimated by the values of x (attributes). It is extremely important that in the predicted model the sum of squares of the errors of the estimated parameters is as small as possible [72]. Finally, the global regression model can be rearranged in the following form:

$$P = \beta_0 + \sum_{i=1}^{K} \beta_i X_i + e \tag{3}$$

where P is the unit price of the apartment sold, logarithmic if the normality of the distribution is not met.

The basic problem of typical methods of statistical analysis, including the OLS technique, is related to the fact that, as a rule, these methods aim to formulate common relationships that exist between the variables under study in different locations [73]. How-

ever, it is problematic and impossible to achieve analyses that are representative of a given location, and the standard OLS regression may be insufficient to correctly identify the attributes that determine property sales prices. In addition, an extremely important issue is the fact that the findings obtained as a result of the OLS technique may be biased due to the heterogeneity of spatial relationships; moreover, in many cases the transactions collected and included in the analysis may be spatially autocorrelated. This phenomenon is directly related to the typical behavior of the average property market participant, who, when selling an apartment, takes into account the transaction prices of comparable housing units that were transacted in the immediate vicinity. The phenomenon of spatial autocorrelation may furthermore result from the fact that locational attributes can affect prices in certain areas in an analogous way [74]. In the case of the analyzed dataset, the occurrence of the phenomenon of spatial autocorrelation of the analyzed prices was checked using Moran's I test.

2.2.2. Geographically Weighted Regression

The solution to the problem arising from the phenomenon of spatial autocorrelation is the geographically weighted regression (GWR) method proposed in 1996 [75]. Within certain limits, the GWR technique can be defined as a kind of extension of the OLS global regression method, with the difference being that the GWR method allows the estimation of local coefficients based on samples within the bandwidth of a local location. Given the above considerations, the GWR model can be presented according to the following formula:

$$P = \beta_0 (x_i, y_i) + \sum_{i=1}^{K} \beta_i (x_i, y_i) X_i + e \quad (4)$$

where:

x_i, y_i—i-th point geographical coordinates,
$\beta_0(x_i, y_i)$—location-specific intersection point,
$\beta_i(x_i, y_i)$—coefficient specific to the location of the point i,
X_i—variable related to $\beta_i(x_i, y_i)$,
K—number of estimated parameters,
e—standard error.

Parameters in the GWR model are estimated in a comparable way to classical techniques; however, an important difference is the assumption according to which weights are taken into account, being conditional on the location of individual observations:

$$\beta(x_i,\ y_i) = \left(X^T W(x_i, y_i) X\right)^{-1} X^T W(x_i,\ y_i) y \quad (5)$$

where $W(x_i,y_i)$ is a diagonal matrix of weights, which are a function of the distance between the location given by the coordinates (x_i, y_i) and the location of each point where the observation occurred.

The weights are usually determined using a function with a shape similar to that of a Gaussian curve, while taking into account the bandwidth of the parameters, which characterizes the spatial range from which the observations are taken into account in the calculations. The GWR results more accurately represent the global model as a result of using a larger bandwidth. As a result of applying the GWR model, a series of points defined by the estimated parameters is obtained, which makes it possible to observe the variation in these parameters in the analyzed area.

A direct comparison of the equations associated sequentially with the OLS model and the GWR model makes it possible to conclude that the global model can be interpreted as a kind of special case of the local model. The most significant difference between the compared models is the assumption that the parameters in the global model are taken as constant, while the coefficients in the model built based on GWR spatially vary. The key process during the implementation of the GWR regression is the calibration of the equation during which the assumption is made that observations occurring close

to the location of a given point have a significantly greater impact on the estimation of certain parameters compared to observations located at a greater distance. The coefficients of the model built using the GWR technique are estimated locally using the weighted least squares method, which consequently results in closer observations having a greater weight compared to observations located at a greater distance [76–79]. In summary, the main difference between the OLS technique compared to the GWR technique is that the parameters in the global model are constant, while in the GWR model the coefficients have location-dependent variability.

3. Results and Discussion

3.1. Characteristics of the Variables Included in the Analysis

As a preliminary step, a synthetic characterization of the dependent variable and independent variables (included in the analysis primarily on the basis of information from real estate offices) was performed, within which basic descriptive statistics were calculated, including the mean, standard deviation and maximum and minimum values (Table 2).

Table 2. Descriptive statistics of dependent and independent variables.

	Mean	σ	Max	Min	Median
Price (PLN/m^2)	7126.45	1689.48	16,000.00	3019.32	6969.70
Number of rooms	2.92	1.07	8.00	1.00	3.00
Surface area (m^2)	53.28	22.20	237.08	10.56	48.80
Floor	2.94	2.51	17.00	−1.00	2.00
Associated premise	0.37	0.59	9.00	0.00	0.00
Distance to shopping center (m)	918.83	769.30	7478.58	0.01	770.24
Distance to tram stop (m)	666.32	824.83	7141.70	13.76	368.67
Distance to park(m)	530.18	497.06	5539.09	0.15	438.09
Distance to city center (m)	3641.53	1751.48	11,328.34	149.43	3451.39
Distance to bus stop (m)	205.51	126.74	1434.71	11.93	181.05
Distance to water (m)	551.48	362.16	1711.63	18.64	461.84
Distance to major roads (m)	978.80	719.23	5340.19	9.23	846.90
Distance to school (m)	678.78	504.87	4387.43	2.92	572.47
Number of observations			6611		

During the initial stage of the conducted analyses, the independent variables were subjected to an initial analysis. The issues of multilinearity between the adopted attributes and skewness defining the measure of asymmetry of the analyzed observations were taken into account in turn. In the study in question, attributes characterized by a skewness value greater than 3 were logarithmically transformed [80]. Then, the OLS regression was estimated with the use of the corresponding VIF (variance inflation factor) values which were simultaneously calculated for the analyzed attributes. Variables characterized by a VIF value greater than 7.5 were removed from the final part of the conducted analysis (Table 3).

3.2. OLS Regression

Based on the results obtained as a result of the OLS global regression model, it can be concluded that most of the variables are statistically significant when the p-value = 1%. The variables that are not statistically significant are F, DS and DPark. The obtained model explains about 23% of the variability of the observed phenomenon. Note that the negative values of the coefficients for factors determined by the measuring distance (e.g., for the trait distance from the center of Poznań—DCC) indicate a positive effect of the trait on the price of the properties included in the study. Variance inflation factor (VIF) coefficients for none of the analyzed attributes exceed the value of 3, which may indicate a lack of collinearity between the variables included in the analysis. Most of the variables received the expected

values of the coefficients; the exception may be the attribute related to the distance of the apartment from the tram stop. The negative impact of this attribute may be related to the noise generated by this mode of transportation (Table 4).

Table 3. Characteristics of qualitative and quantitative variables applied in the model.

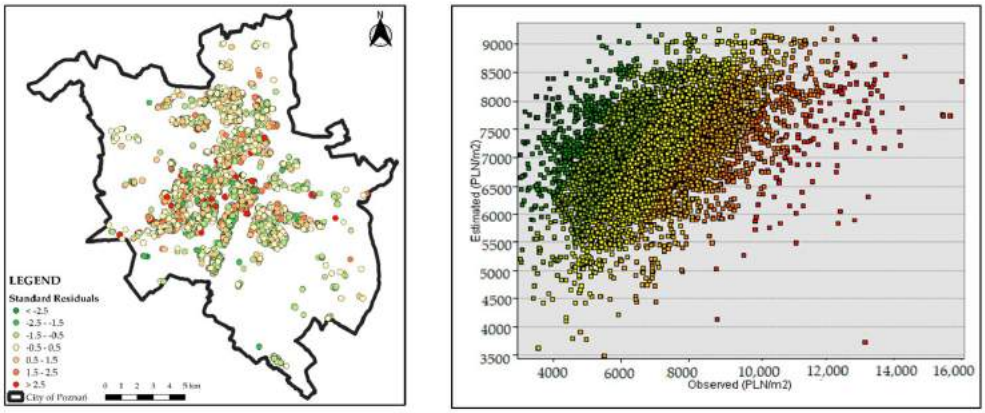
Feature	Symbol	Feature Description	Form
Price	P	Housing price (PLN/m^2)	Standard
Rooms	NR	Number of rooms	Standard
Surface area	SA	Surface area of the housing unit (m^2)	Standard
Floor	F	Floor number	Standard
Associated premise	BT	Number of associated premises	Standard
Shopping center	DS	Distance to the shopping center (m)	Logarithmic
Tram stop	DT	Distance to a tram stop (m)	Logarithmic
Park	DPark	Distance to a park (m)	Logarithmic
City center	DCC	Distance to the center of Poznań (m)	Standard
Bus stop	DB	Distance to a bus stop (m)	Standard
Water	DW	Distance to surface water (m)	Standard
Major roads	DMR	Distance to major roads (m)	Standard
School	DSch	Distance from educational institutions (m)	Standard

Table 4. Summary of ordinary least squares (OLS) regression results.

	Coefficient	Standard Error	T-Value	*p*-Value	VIF
Intercept	9067.4456	211.9445	42.7822	0.0000 *	-
NR	−571.0740	26.2763	−21.7334	0.0000 *	2.3694
SA	−3.6035	1.2695	−2.8386	0.0046 *	2.3928
F	12.7004	7.4552	1.7036	0.0885	1.0525
BT	−180.8261	31.7043	−5.7035	0.0000 *	1.0616
DS	−39.2856	52.0490	−0.7548	0.4504	1.1284
DT	384.7857	60.1649	6.3955	0.0000 *	2.0067
DPark	−65.5485	45.8887	−1.4284	0.1532	1.1633
DCC	−0.1962	0.0173	−11.3365	0.0000 *	2.7684
DB	0.2517	0.1499	1.6791	0.0000 *	1.0882
DW	−0.2631	0.0601	−4.3795	0.0000 *	1.4262
DMR	0.1089	0.0313	3.4784	0.0005 *	1.5280
DSch	−0.1133	0.0408	−2.7737	0.0056 *	1.2811
	Number of Observations			6611	
	Multiple R-Squared			0.2330	
	Adjusted R-Squared			0.2316	
	AICc			17,035.3480	

* An asterisk next to a number indicates a statistically significant *p*-value ($p < 0.01$).

In addition, the OLS regression analysis carried out made it possible to determine, on the basis of the model built, the estimated prices of the dwellings analyzed. The vast majority of the values of the standardized residuals indicating differences between the observed and estimated prices were in the −0.5 to 0.5 range (2868 observations). At the extremes, the values of standardized residuals amounted to −3.13 (the difference between the observed and estimated price was −4649.13 PLN) and 6.38 (the difference between the observed and estimated price was −9444.06 PLN) (Figure 4).



(**a**) (**b**)

Figure 4. (**a**) OLS standard residuals. (**b**) Difference between the observed and estimated values.

3.3. GWR Regression

The GWR regression analysis was applied after first identifying the phenomenon of spatial autocorrelation of the analyzed prices; therefore, for the analyzed set of housing units, the value of Moran's I test was calculated. Based on the results obtained, defined by both the values of the test itself and the *p*-value, it can be concluded that the property prices are spatially clustered and are characterized by positive spatial autocorrelation, and the results obtained are statistically significant (Table 5).

Table 5. Measures of spatial autocorrelation for the dwelling prices.

Moran's Index	0.3904
Expected Index	−0.0002
Variance	0.0001
z-score	54.7223
p-value	0.0000

For additionally enriching the analysis on the basis of the results obtained from the OLS regression, the phenomenon of spatial autocorrelation was checked using Moran's I test for OLS residuals. Considering the results including the z-score variance of 48.5599, there is less than 1% probability that the analyzed clustering pattern may be the result of random chance (Table 6).

Table 6. Measures of spatial autocorrelation for the OLS residuals.

Moran's Index	0.3464
Expected Index	−0.0002
Variance	0.0001
z-score	48.5599
p-value	0.0000

MGWR 2.2 software was used to perform the geographically weighted regression [81]. The results obtained following GWR indicate a significant difference in the range of results obtained with respect to global regression (OLS). The value of the adjusted R-Squared is 0.477 (OLS: 0.2316), and the value of AICc is equal to 15597.432 (OLS: 17035.3480). Based on

the values presented thus far, we can conclude that the GWR technique has a more efficient modeling quality with respect to the OLS technique. Taking into account the specifics of this type of regression, the number of observations (defined by the percentage value) that are statistically significant based on the T-value (adj. critical t value is equal to 3.384) was further defined. The largest number of statistically significant observations was defined for the surface area feature (10.88%), while the smallest was defined for the distance to surface water feature (2.24%). Furthermore, the difference with OLS regression is the ability to analyze the phenomenon of collinearity of the analyzed attributes for each observation. The highest number of cases with a VIF value greater than 7.5 was identified for the DCC attribute (6178 observations); for the floor attribute all observations had a VIF value less than 7.5 (Table 7).

Table 7. Summary of squares (GWR) regression results (Group 1).

	Mean	SD	Min	Median	Max	Percent of Significant Cases at 95%	Percent of Cases with Local VIF > 7.5
Intercept	−6.208	57.630	−451.945	−0.312	503.614	3.43%	-
NR	−0.170	0.231	−1.004	−0.165	0.640	7.94%	10.29%
SA	−0.235	0.309	−1.310	−0.239	0.942	10.88%	9.08%
F	0.064	0.154	−0.392	0.039	0.830	3.84%	0.00%
BT	−0.032	0.579	−3.730	−0.032	33.803	6.84%	0.64%
DS	0.015	8.460	−72.226	−0.012	126.927	2.87%	73.21%
DT	3.717	27.158	−23.143	0.116	302.379	4.77%	51.88%
DPark	−0.289	1.667	−17.968	0.014	9.381	3.99%	62.00%
DCC	1.133	49.423	−390.291	0.229	499.569	3.15%	93.45%
DB	0.116	0.804	−5.035	0.012	10.587	2.44%	19.63%
DW	−0.311	1.954	−19.191	−0.287	11.336	2.24%	68.40%
DMR	−1.406	22.238	−143.849	−0.092	283.861	5.19%	87.49%
DSch	−0.604	3.352	−39.026	−0.127	24.271	4.39%	70.17%
Number of Observations						6611	
Multiple R-Squared						0.549	
Adjusted R-Squared						0.477	
AIC						15,309.007	
AICc						15,597.432	
Bandwidth used						167.000	

Based on a preliminary analysis of the average values of the parameters of the GWR model, we can conclude that the nature of the impact of most attributes is comparable to the estimates of the OLS model (the difference is in the DS, DCC and DMR attributes). However, it should be emphasized how important the minimum and maximum values of the coefficients are, which indicate how significantly the impact of a given attribute can vary within the analyzed area. The results obtained confirm the heterogeneity and complexity of the market under study, and underscore the validity of including the exact geographic location of observations in the analysis.

The model obtained with the GWR regression revealed that the most significant determinant of unit transaction prices for the housing market in Poznań as a whole was the variable related to floor area (SA). The significance of this variable was confirmed for 719 observations (a total of 6611 observations were taken). The SA attribute has, as expected, a negative impact on the amount of the unit transaction price of apartments in almost the entire analyzed area. In general, the strongest negative impact of the analyzed determinant (FA) can be observed among transactions located in the southeastern part of the city. However, the negative correlation between the analyzed attribute and price decreases in the center and northeastern part of the city, where a positive impact of the

analyzed independent variable on the dependent variable can be observed in selected areas. This phenomenon is observed, among others, in the district of Poznań—Old Town, which is considered, among other things, to be due to its location which is prestigious. In the case studied, this fact can directly result in an increase in the motivation of buyers to pay a higher price for each additional square meter of apartment space. At the same time, however, it should be emphasized that in many cases the positive correlation is statistically insignificant, which directly results in the fact that the correlations described above cannot be considered as undeniably certain (Figure 5).

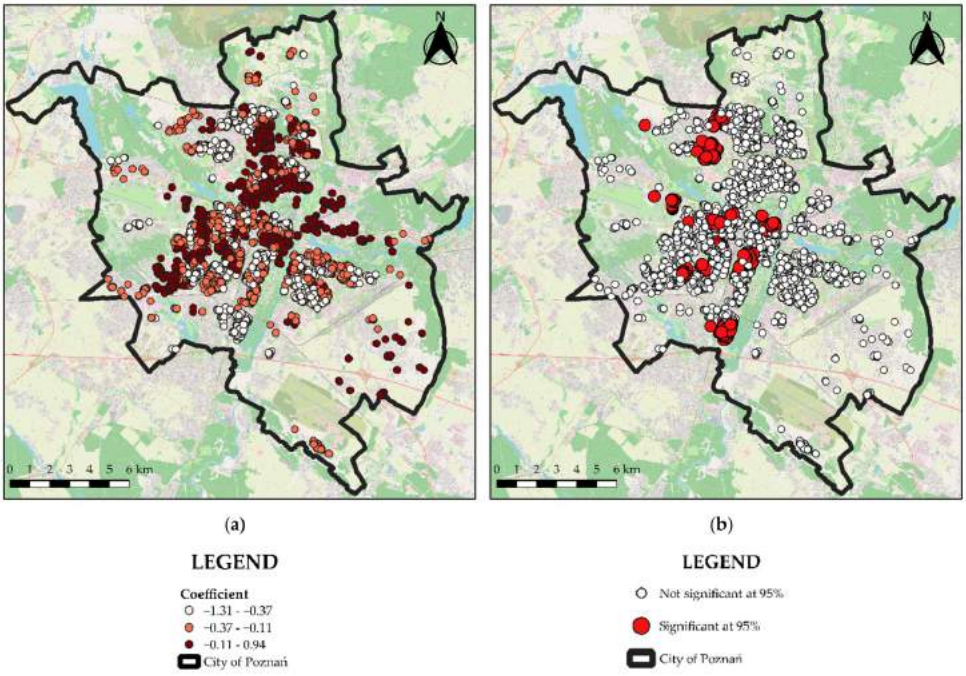


Figure 5. (**a**) Local estimated coefficients—SA. (**b**) Statistical significance of estimated coefficients—SA.

Among the locational characteristics, interesting results can be observed for the determinant related to distance from a bus stop. The number of statistically significant observations is small (161), while if the attribute is significant it is mostly in locations at a considerable distance from the city center.

This correlation may indicate that this attribute is particularly important for homebuyers, who in the future will have to use public transportation for an efficient connection to the center. For the aforementioned observations, in most situations the coefficient has a negative value whereby it can be concluded that in areas located on the outskirts of the city, the higher price is obtained by apartments located closer to the bus stop (Figure 6).

In comparison, the variable related to accessibility to a tram stop was statistically significant for 315 observations located in the city center, in most cases along the course of existing tram lines (Figure 7).

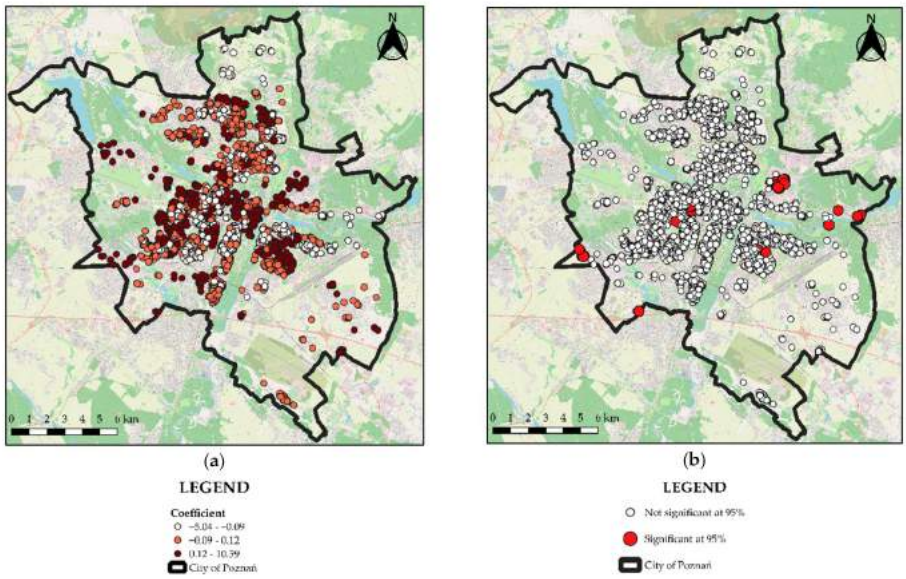


Figure 6. (**a**) Local estimated coefficients—DB. (**b**) Statistical significance of estimated coefficients—DB.

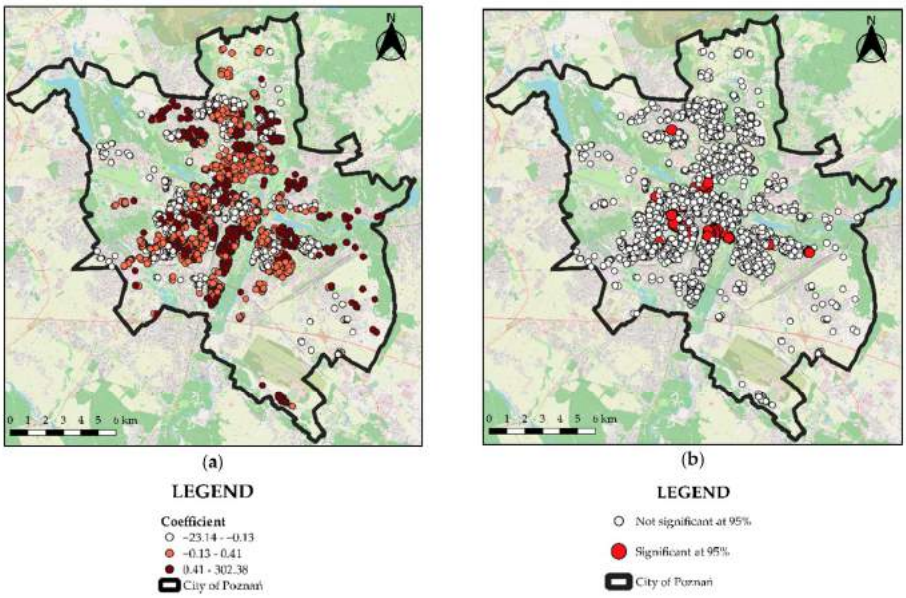


Figure 7. (**a**) Local estimated coefficients—DT. (**b**) Statistical significance of estimated coefficients—DT.

Due to the number of analyzed attributes and the complexity of the analyzed phenomenon, the remaining estimation results of the GWR model are presented in the Supplementary Materials (Figures S1–S9).

In order to systematize the analysis carried out and to present in a clear form the results obtained for the housing transaction market in Poznań, the number of significant attributes that determined the sales price is presented for each housing unit included in the analysis. The vast majority of transactions that were characterized by a higher number of relevant attributes (4–9) were located in the city center. This phenomenon may be due to the fact that the residential real estate market in this area is the most developed and most of the analyzed transactions were concluded within it (Figure 8). Moreover, it is worth noting that the results obtained confirm the phenomenon according to which certain variables can be consolidated into a single characteristic by market participants. An example is the characteristics related to the number of rooms and area of the apartment, which on a global scale have a significant impact on the level of transaction prices. On the local scale, however, in a small number of cases both price determinants are simultaneously significant.

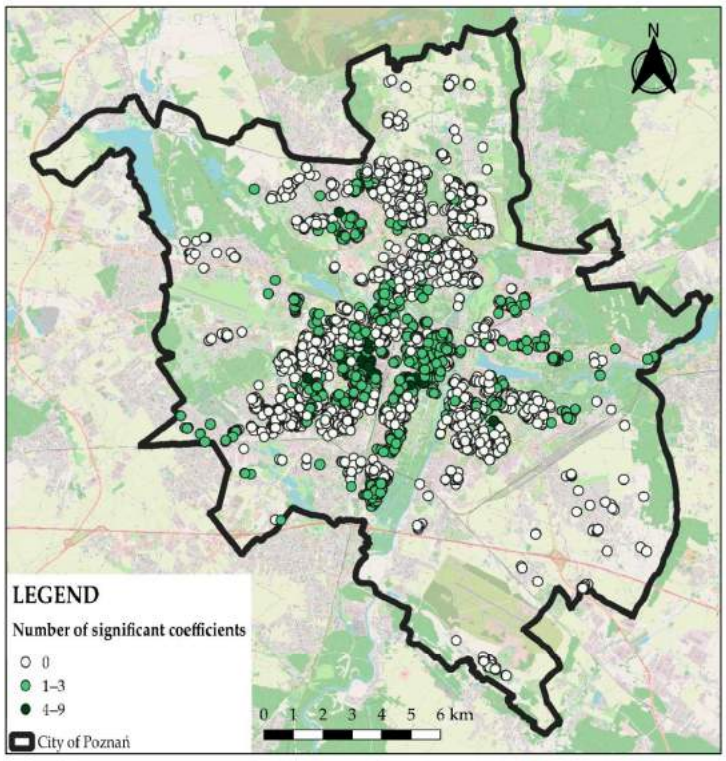


Figure 8. Number of significant coefficients for each dwelling at 95%.

4. Conclusions

The mechanisms taking place within the residential real estate market are essentially determined by two groups of factors: microeconomic and macroeconomic. The undisputed majority of existing scientific studies take into account in their structure a wide range of microeconomic features [82–85] or a single factor that is a fundamental element of the

analyses performed, which belongs to this group [86–90]. This study attempts to identify the determinants (belonging to the first group) that significantly influence prices within the housing market in Poznań. The factors belonging to the second group were only some kinds of external determinants, which, due to the need to present a detailed characterization of the market, were taken into account in Section 1.2 of this work.

An indisputable advantage of our study is its reliability, since the source data obtained and recorded came directly from the market. Analyses of this kind can be characterized by a much wider application compared to studies based, for example, on data derived from the bidding market or the rental market [91–93]. Additionally, with respect to some of the comparable studies conducted within selected Polish cities [94–97], the present analysis in its structure covers a relatively long period of time which also increases the applicability of our results.

The characteristics of localization issues in its structure should be defined by spatial autocorrelation analysis [98]. The key advantage of spatial regression models (e.g., GWR) compared to standard regression models (OLS) is that in their structure they take into account local spatial relationships, which allow results to be achieved that are characterized by a much greater degree of detail at the local level [99]. This regularity is confirmed by the GWR regression results we obtained, according to which the coefficients for each attribute included in the analysis are diverse and heterogeneous within the study area. The adoption of homogeneous conclusions as a result of OLS regression for the entire study area would constitute a serious error, which could consequently lead to fundamental cognitive errors. In addition, it is worth noting that the GWR analysis made it possible to identify (apart from local markets characterized by individual conditions) certain characteristics whose mode of influence is universal for the greater part of the city. Within the city of Poznań, these are variables related primarily to the physical characteristics of the apartment, i.e., the number of rooms and the area.

Despite the presented advantages of the methodology used in this study, it obviously has some limitations. First, gathering more precise information about the analyzed properties could make the analysis more complex. The use of other types of methods and the inclusion of additional characteristics related to, for example, the standard of housing units in the study could directly lead to a greater accuracy of the model built [100]. The process of selecting the appropriate attributes for analysis is also an undeniable problem. Although the variables were selected primarily on the basis of information obtained from local real estate offices, there can be no absolute guarantee that these are the most relevant attributes within the local market. There is a real possibility that an important attribute may have been overlooked and that the analysis includes an attribute that should not have been included.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/land12010125/s1. Figure S1. (a) Local estimated coefficients—Number of rooms. (b) Statistical significance of estimated coefficients—Number of rooms. Figure S2. (a) Local estimated coefficients—Floor number. (b) Statistical significance of estimated coefficients—Floor number. Figure S3. (a) Local estimated coefficients—Number of associated premises. (b) Statistical significance of estimated coefficients—Number of associated premises. Figure S4. (a) Local estimated coefficients—Distance to the shopping center. (b) Statistical significance of estimated coefficients—Distance to the shopping center. Figure S5. (a) Local estimated coefficients—Distance to park. (b) Statistical significance of estimated coefficients—Distance to park. Figure S6. (a) Local estimated coefficients—Distance to the center of Poznań. (b) Statistical significance of estimated coefficients—Distance to the center of Poznań. Figure S7. (a) Local estimated coefficients—Distance to surface water. (b) Statistical significance of estimated coefficients—Dis-tance to surface water. Figure S8. (a) Local estimated coefficients—Distance to major roads. (b) Statistical significance of estimated coefficients—Dis-tance to major roads. Figure S9. (a) Local estimated coefficients—Distance from educational institutions. (b) Statistical significance of estimated coeffi-cients—Distance from educational institutions.

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Supplementary material

Remaining local coefficient estimates of GWR model

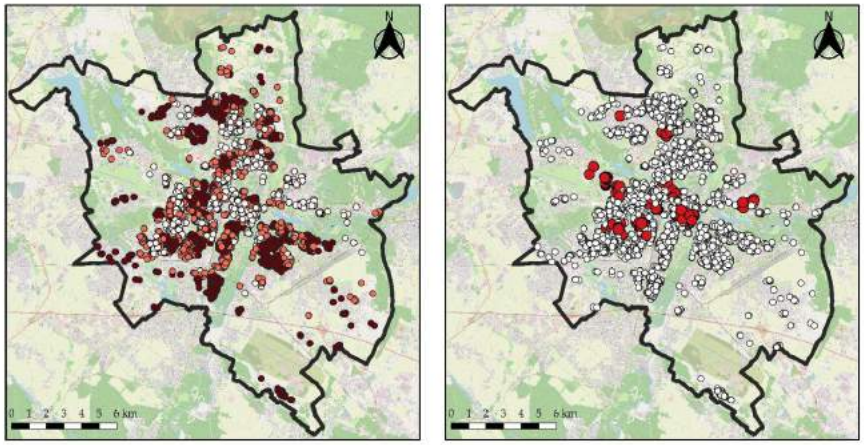


Figure S1. (a) Local estimated coefficients – Number of rooms. **(b)** Statistical significance of estimated coefficients – Number of rooms.

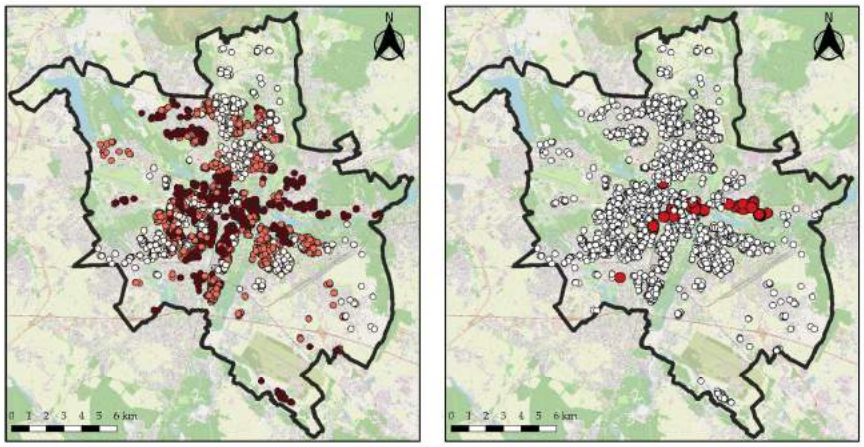


Figure S2. (a) Local estimated coefficients – Floor number. **(b)** Statistical significance of estimated coefficients – Floor number.

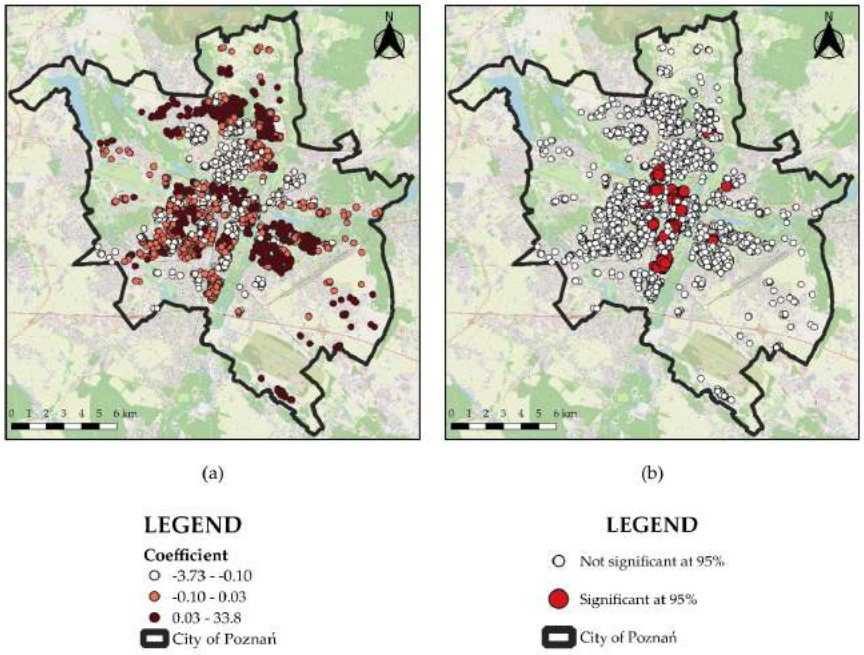


Figure S3. (a) Local estimated coefficients – Number of associated premises. **(b)** Statistical significance of estimated coefficients – Number of associated premises.

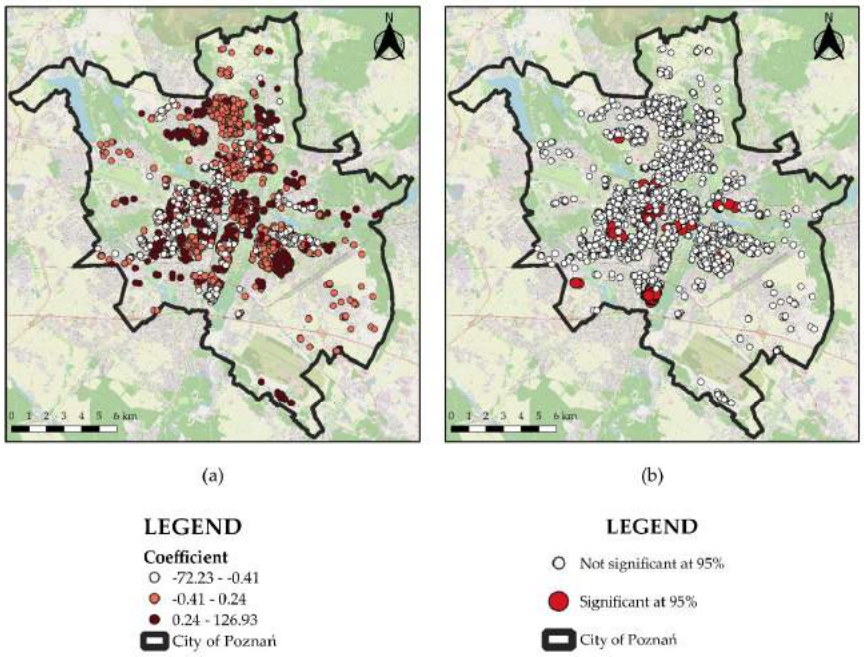


Figure S4. (a) Local estimated coefficients – Distance to the shopping center. **(b)** Statistical significance of estimated coefficients – Distance to the shopping center.

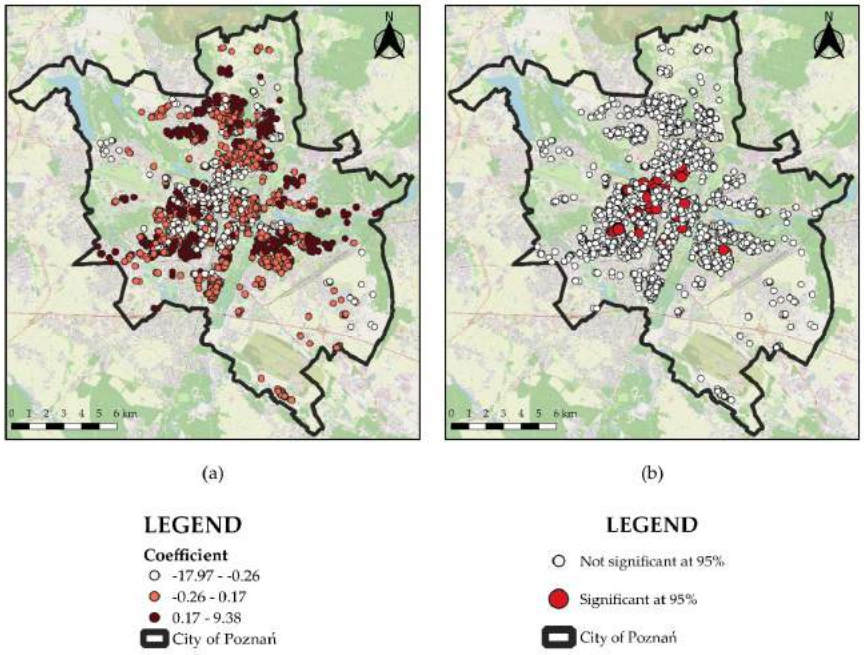


Figure S5. (a) Local estimated coefficients – Distance to park. **(b)** Statistical significance of estimated coefficients – Distance to park.

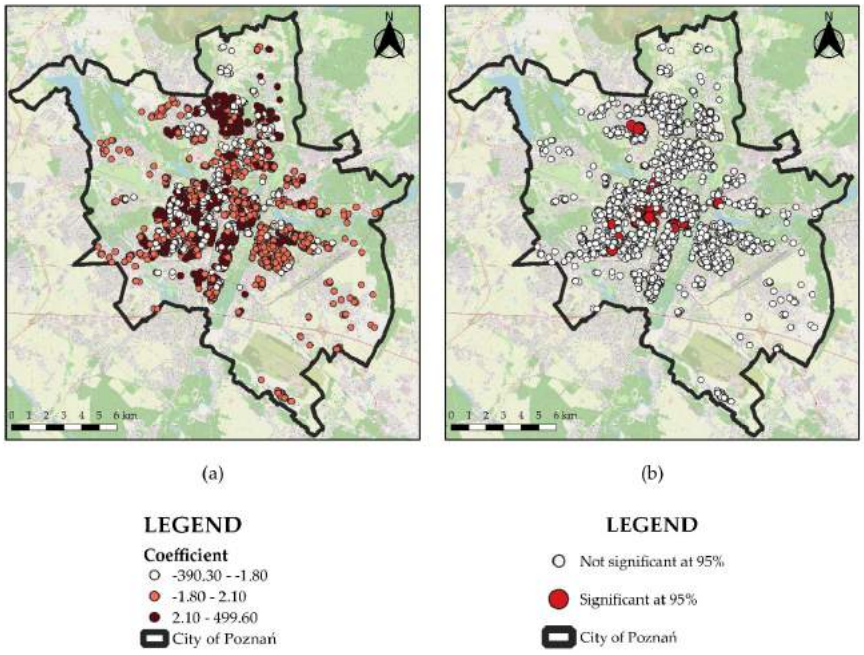


Figure S6. (a) Local estimated coefficients – Distance to the center of Poznań. **(b)** Statistical significance of estimated coefficients – Distance to the center of Poznań.

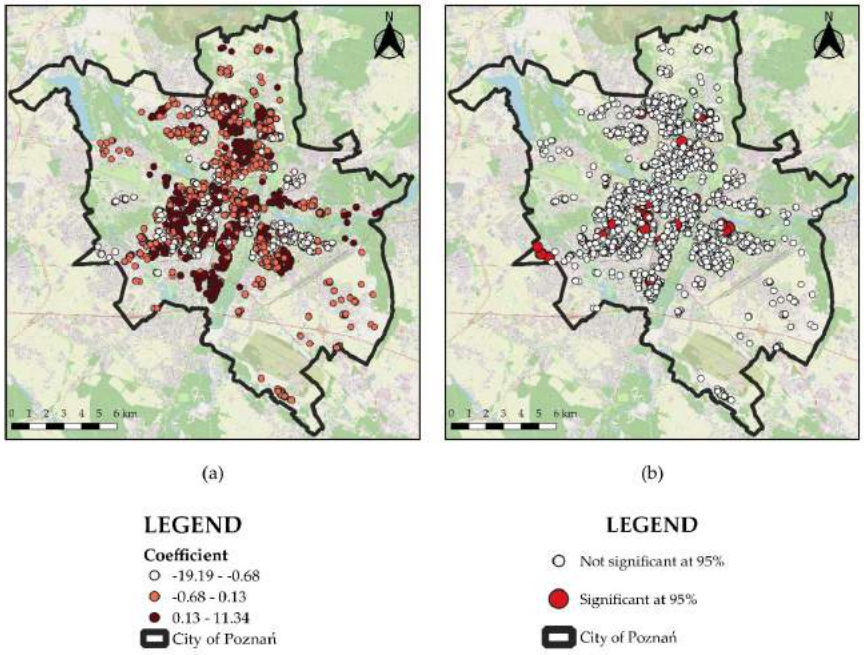


Figure S7. (a) Local estimated coefficients – Distance to surface water. **(b)** Statistical significance of estimated coefficients – Distance to surface water.

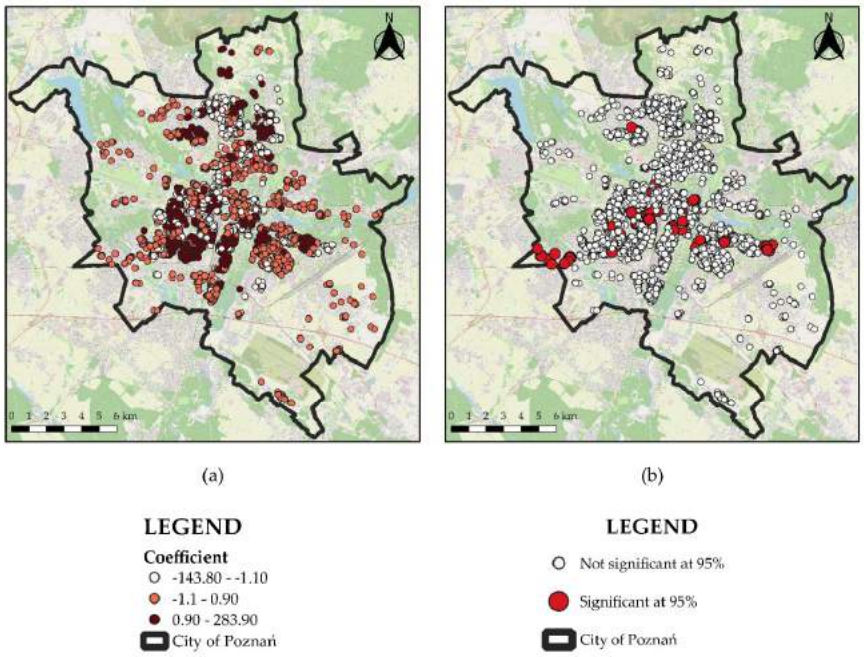
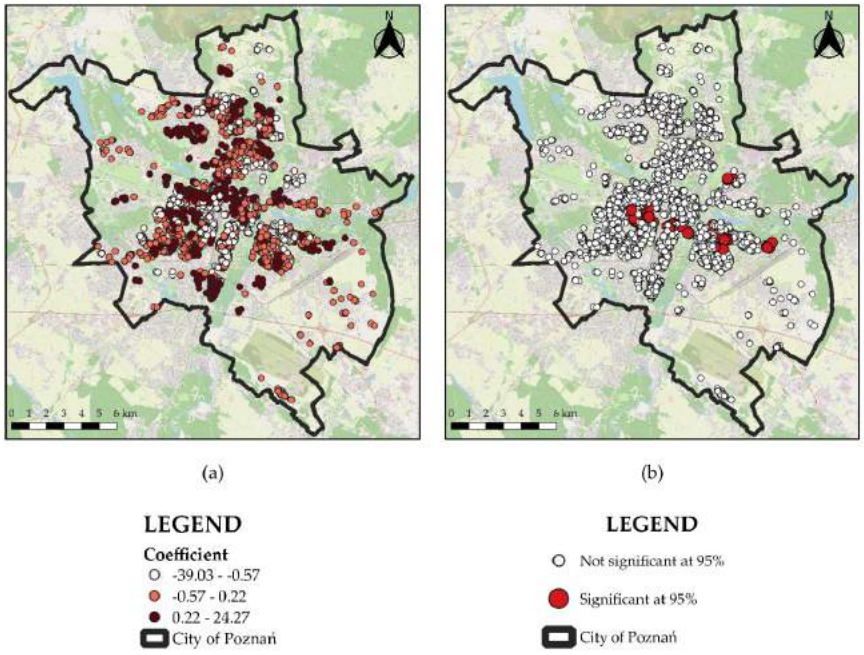


Figure S8. (a) Local estimated coefficients – Distance to major roads. **(b)** Statistical significance of estimated coefficients – Distance to major roads.



(a)

LEGEND

Coefficient
-39.03 - -0.57
-0.57 - 0.22
0.22 - 24.27
City of Poznań

(b)

LEGEND

Not significant at 95%
Significant at 95%
City of Poznań

Figure S9. (a) Local estimated coefficients – Distance from educational institutions. **(b)** Statistical significance of estimated coefficients – Distance from educational institutions.

6. Oświadczenia doktoranta oraz współautorów dotyczących ich wkładu w przygotowanie opublikowanych prac naukowych

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Poznań 24 kwietnia 2023 r.

OŚWIADCZENIE DOKTORANTA

Niniejszym oświadczam, że mój wkład autorski w publikację:

Chwiałkowski, C.; Zydroń, A. Socio-Economic and Spatial Characteristics of Wielkopolski National Park: Application of the Hedonic Pricing Method. Sustainability 2021, 13, 5001. https://doi.org/10.3390/su13095001

wynosi 80%. Mój wkład polegał na: opracowaniu koncepcji badań, zgromadzeniu danych, wyborze odpowiedniej metodyki, przeprowadzeniu analiz formalnych, opracowaniu wyników oraz przygotowaniu wstępnej i ostatecznej wersji manuskryptu (po uwagach recenzentów).

Podpis .....

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wynosi:

Imię i nazwisko współautora	Wkład współautora (%)	Data	Podpis
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wynosi 80%. Mój wkład polegał na: opracowaniu koncepcji badań, zgromadzeniu danych, wyborze odpowiedniej metodyki, przeprowadzeniu analiz formalnych, opracowaniu wyników oraz przygotowaniu wstępnej i ostatecznej wersji manuskryptu (po uwagach recenzentów).

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mgr inż. Cyprian Chwiałkowski
Katedra Melioracji, Kształtowania Środowiska
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Uniwersytet Przyrodniczy w Poznaniu

Poznań 24 kwietnia 2023 r.

OŚWIADCZENIE DOKTORANTA

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Podpis .....

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prof. UPP dr hab. Dariusz Kayzer	10	24.04.2023 r.	