# **Supplementary: Environmental Data**

We have collected 13 types of global ecological data (Supplementary Table 1), including methane (CH4), evapotranspiration (ET), Enhanced Vegetation Index (EVI), gross primary productivity (GPP), human footprint (HFP), impervious surface area (ISA), surface temperature (LST), normalized vegetation index (NDVI), net ecosystem productivity (NEP), net primary productivity (NPP), precipitation (PRE), atmospheric pressure (PRES), and temperature (TMP).

*Supplementary Table 1. Ecological Data Basic Information*

|  |  |  |
| --- | --- | --- |
| Data Name | Temporal resolution | spatial resolution |
| CH4 | Daily,2003-2020 | 0.1° |
| ET | 8days,2000-2023 | 1km |
| EVI | 8days,2000-2024 | 250m |
| GPP | 8days,2000-2024 | 500m |
| HFP | Yearly,2000-2018 | 1km |
| ISA | Yearly.2000-2021 | 30m |
| LST | Daily,2000-2020 | 1km |
| NDVI | 8days,2000-2024 | 250m |
| NEP | Daily,1981-2019 | 0.072727° |
| NPP | 8days,2000-2024 | 500m |
| PRE | Daily,2000-2020 | 0.5° |
| PRES | Daily,2000-2020 | 0.5° |
| TMP | Daily,2000-2020 | 0.5° |

ET, EVI, GPP, LST, NDVI, and NPP data are extracted from the products in the Reference1. The ISA data is obtained from the products in the Reference2. The HFP data is extracted from the products in the Reference3. NEP, PRE, PRES, and TMP are obtained from the products in the Reference4.

To facilitate statistical analysis, the spatial resolutions of all ecological data were resampled to 1km. The research period was from 2003 to 2022. The original data sources were available from 2000 to 2019 or 2020. A linear regression-based extrapolation approach was applied to extend the data to 2022. Furthermore, since most socio-economic data is annual, the time granularity of the ecological data is standardized as the annual mean. In other words, the daily and the eight-day values of the ecological variables were standardized as the annual mean values. The ecological data is merged with the selected World Development Indicators as a unified dataset, which is accessible at the following link: <https://github.com/Zhangyudan0208/ml-bigdata-justice-iam.git>.

**Supplementary: Socioeconomic Justice and Equity Data**

The socioeconomic justice and equity data source is the World Development Indicators (WDI) data catalog (<https://datacatalog.worldbank.org/dataset/world-development-indicators> ). The catalog collects more than seven hundred variables, most extending from 2000 to 2022. However, many countries contain missing data, and some have missing data in some years. Li and her colleagues5 filled in the missing data values, supporting their research paper on Diagnosing Syndromes of Biosphere-Atmosphere-Socioeconomic Change. The missing-value-filled data is accessible at <https://zenodo.org/records/14876723>. This dataset is the source from which we analyzed and extracted the justice and equity variables.

This research thoroughly analyzed the world development indicators. Global justice and equity are reflected in many world development indicators, both between and within countries6. For example, justice-related variables include infant mortality rate, life expectancy, absolute poverty (surviving on less than $2.15 or $3.65 per day), and undernourishment7. Justice also affects relative poverty indicators, such as people practicing open defecation, people lacking access to safely managed sanitation services, drinking water, health facilities, school education, etc8,9. Gender inequity, sexual orientation, and culturally accepted forms of prejudice and discrimination lead to justice concerns10,11. Many other variables affect global justice characteristics, including the impact of external debt on economic growth, real gross national income per capita, terms of trade, economic openness, commodity price volatility, and government management effectiveness12.

Based on the literature reviews, 64 world development indicators are selected and grouped into eight dimensions: Economic, Education, Environmental, Equity Factors, Governance Effectiveness, Resources, Trade Elements, and Human Wellbeing. These indicators were renamed according to their semantic meanings (Supplementary Table 2). All socioeconomic data used in this study are structured with countries as the spatial unit and annual resolution as the temporal unit. They are merged with the ecological data as a unified dataset, which is accessible at the following link, <https://github.com/Zhangyudan0208/ml-bigdata-justice-iam.git>.

Supplementary Table 2. Sixty-four World Development Indicators, Abbreviations, and Descriptions

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Abbreviation** | **Description** | **Series Code in WDI\_2003\_2022** |
| 1 | EcGDPGr | GDP growth (annual %) | NY.GDP.MKTP.KD.ZG |
| 2 | EcGDPPc | GDP per capita (current US$) | NY.GDP.PCAP.CD |
| 3 | EcPtEMPFe | Part time employment, female (% of total female employment) | SL.TLF.PART.FE.ZS |
| 4 | EcPtEMPMa | Part time employment, male (% of total male employment) | SL.TLF.PART.MA.ZS |
| 5 | EcMKTDc%GDP | Market capitalization of listed domestic companies (% of GDP) | CM.MKT.LCAP.GD.ZS |
| 6 | EcTAX%GDP | Tax revenue (% of GDP) | GC.TAX.TOTL.GD.ZS |
| 7 | EcAFF%GDP | Agriculture, forestry, and fishing, value added (% of GDP) | NV.AGR.TOTL.ZS |
| 8 | EcDEB%Ex | Debt service (PPG and IMF only, % of exports of goods, services and primary income) | DT.TDS.DPPF.XP.ZS |
| 9 | EcINF% | Inflation, consumer prices (annual %) | FP.CPI.TOTL.ZG |
| 10 | EcAFFGr | Agriculture, forestry, and fishing, value added (annual % growth) | NV.AGR.TOTL.KD.ZG |
| 11 | EcMANGr | Manufacturing, value added (annual % growth) | NV.IND.MANF.KD.ZG |
| 12 | EcSERGr | Services, value added (annual % growth) | NV.SRV.TOTL.KD.ZG |
| 13 | EcESDS% | External debt stocks (% of GNI) | DT.DOD.DECT.GN.ZS |
| 14 | EcINSF%%Exp | Insurance and financial services (% of service exports, BoP) | BX.GSR.INSF.ZS |
| 15 | EcURPop% | Urban population (% of total population) | SP.URB.TOTL.IN.ZS |
| 16 | EcPOPTot | Population, total | SP.POP.TOTL |
| 17 | EdENRPr | School enrollment, primary (% gross) | SE.PRM.ENRR |
| 18 | EdPTRatio | Pupil-teacher ratio | SE.TER.ENRL.TC.ZS |
| 19 | EdGOVEx% | Government expenditure on education, total (% of government expenditure) | SE.XPD.TOTL.GB.ZS |
| 20 | EdNOSPr | Children out of school (% of primary school age) | SE.PRM.UNER.ZS |
| 21 | EnCO2pUS$ | CO2 emissions (kg per 2015 US$ of GDP) | EN.ATM.CO2E.KD.GD |
| 22 | EnCO2fIND | CO2 emissions from manufacturing industries and construction (% of total fuel combustion) | EN.CO2.MANF.ZS |
| 23 | EnGHG%Ch | Total greenhouse gas emissions (% change from 1990) | EN.ATM.GHGT.ZG |
| 24 | EnCO2Pc | CO2 emissions (metric tons per capita) | EN.ATM.CO2E.PC |
| 25 | EnFFEC% | Fossil fuel energy consumption (% of total) | EG.USE.COMM.FO.ZS |
| 26 | EnPM2.5 | PM2.5 air pollution, mean annual exposure (micrograms per cubic meter) | EN.ATM.PM25.MC.M3 |
| 27 | EnRENEC% | Renewable energy consumption (% of total final energy consumption) | EG.FEC.RNEW.ZS |
| 28 | EqGINI | Gini index | SI.POV.GINI |
| 29 | EqCPIASp | CPIA social protection rating (1=low to 6=high) | IQ.CPA.PROT.XQ |
| 30 | EqINCL20 | Income share held by lowest 20% | SI.DST.FRST.20 |
| 31 | EqINTU% | Individuals using the Internet (% of population) | IT.NET.USER.ZS |
| 32 | EqSMDW% | People using safely managed drinking water services (% of population) | SH.H2O.SMDW.ZS |
| 33 | EqSMSS% | People using safely managed sanitation services (% of population) | SH.STA.SMSS.ZS |
| 34 | EqUNNU% | Prevalence of undernourishment (% of population) | SN.ITK.DEFC.ZS |
| 35 | EqFE2MRatio | Ratio of female to male labor force participation rate (%) (modeled ILO estimate) | SL.TLF.CACT.FM.ZS |
| 36 | EqPOV215% | Poverty headcount ratio at $2.15 a day (2017 PPP) (% of population) | SI.POV.DDAY |
| 37 | EqDEFec%Ur | People practicing open defecation, urban (% of urban population) | SH.STA.ODFC.UR.ZS |
| 38 | EqPOV365 | Poverty headcount ratio at $3.65 a day (2017 PPP) (% of population) | SI.POV.LMIC |
| 39 | GoCPIADe | CPIA debt policy rating (1=low to 6=high)；Debt policy assesses whether the debt management strategy is conducive to minimizing budgetary risks and ensuring long-term debt sustainability. | IQ.CPA.DEBT.XQ |
| 40 | GoEFF | Government Effectiveness: Estimate | GE.EST |
| 41 | GoPS&AV | Political Stability and Absence of Violence/Terrorism: Estimate | PV.EST |
| 42 | GoREGQu | Regulatory Quality: Estimate | RQ.EST |
| 43 | GoCPIAEc | CPIA economic management cluster average (1=low to 6=high) | IQ.CPA.ECON.XQ |
| 44 | GoRNDEx%GDP | Research and development expenditure (% of GDP) | GB.XPD.RSDV.GD.ZS |
| 45 | GoODA%Ex | Net ODA received (% of central government expense) | DT.ODA.ODAT.XP.ZS |
| 46 | ReARALa% | Arable land (% of land area) | AG.LND.ARBL.ZS |
| 47 | ReTNRR%GDP | Total natural resources rents (% of GDP) | NY.GDP.TOTL.RT.ZS |
| 48 | ReFORLa% | Forest area (% of land area) | AG.LND.FRST.ZS |
| 49 | TrAGR%MExp | Agricultural raw materials exports (% of merchandise exports) | TX.VAL.AGRI.ZS.UN |
| 50 | TrAGR%MImp | Agricultural raw materials imports (% of merchandise imports) | TM.VAL.AGRI.ZS.UN |
| 51 | TrSTOCK%GDP | Stocks traded, total value (% of GDP) | CM.MKT.TRAD.GD.ZS |
| 52 | TrCACB%GDP | Current account balance (% of GDP) | BN.CAB.XOKA.GD.ZS |
| 53 | TrICTExp | ICT service exports (% of service exports, BoP) | BX.GSR.CCIS.ZS |
| 54 | TrFDINout%GDP | Foreign direct investment, net outflows (% of GDP) | BM.KLT.DINV.WD.GD.ZS |
| 55 | TrFDINin%GDP | Foreign direct investment, net inflows (% of GDP) | BX.KLT.DINV.WD.GD.ZS |
| 56 | TrPREM%GDP | Personal remittances, received (% of GDP) | BX.TRF.PWKR.DT.GD.ZS |
| 57 | WeL50Inc | Proportion of people living below 50 percent of median income (%) | SI.DST.50MD |
| 58 | WeUnEMP% | Unemployment, total (% of total labor force) (modeled ILO estimate) | SL.UEM.TOTL.ZS |
| 59 | WeFERTRa | Fertility rate, total (births per woman) | SP.DYN.TFRT.IN |
| 60 | WeHOSBed | Hospital beds (per 1,000 people) | SH.MED.BEDS.ZS |
| 61 | WeLIFEx | Life expectancy at birth, total (years) | SP.DYN.LE00.IN |
| 62 | WeMORTU5 | Mortality rate, under-5 (per 1,000 live births) | SH.DYN.MORT |
| 63 | WePOP65 | Population ages 65 and above (% of total population) | SP.POP.65UP.TO.ZS |
| 64 | WeGNI% | GNI per capita growth (annual %) | NY.GNP.PCAP.KD.ZG |

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