Sherboyev Abbos Sherboyevich
Master's Student, Samarkand State University named after Sharof Rashidov
Malikov Musakhon Islomkhonovich
Doctoral Student, Samarkand State University named after Sharof Rashidov
Rashidov Sheroz Zafar ogli
Master's Student, Samarkand State University named after Sharof Rashidov

SIGNIFICANCE AND PROSPECTS OF THE R. MURRAY-RUST METHODOLOGY IN EVALUATING IRRIGATION SYSTEM EFFICIENCY AND MELIORATIVE SUSTAINABILITY OF THE SAMARKAND REGION

Abstract: *This study investigates the application prospects and systemic significance of the diagnostic methodology developed by R. Murray-Rust for evaluating irrigation infrastructure and land reclamation efficiency across the Samarkand region of Uzbekistan. Operating under conditions of severe regional water scarcity and accelerating secondary soil salinization within the Zarafshan River Basin, traditional hydraulic assessments often fail by treating water distribution networks as isolated engineering channels rather than dynamic socio-technical systems. The R. Murray-Rust framework introduces a diagnostic hierarchy focusing on four operational indicators: adequacy, reliability, equity, and efficiency. By translating physical water losses into spatial hydraulic pressures, this methodology clarifies the causal links between unlined canal filtration, the formation of localized subsoil groundwater mounds, and subsequent root-zone waterlogging. Integrating these indicators provides land managers with an analytical foundation to mitigate water delivery imbalances, optimize leaching schedules, and lower seasonal collector-drainage maintenance costs, establishing a replicable framework for digital soil-water monitoring and precision land reclamation in semi-arid zones.*

Keywords: *R. Murray-Rust methodology, irrigation efficiency, meliorative diagnostics, filtration coefficient, Samarkand region, Zarafshan River Basin, adequacy, reliability, equity*.

Шербоев Аббос Шербоевич
магистрант Самаркандского государственного университета имени Шарофа Рашидова

Маликов Мусахон Исломхонович
докторант Самаркандского государственного университета имени Шарофа Рашидова

Рашидов Шероз Зафар угли
магистрант Самаркандского государственного университета имени Шарофа Рашидова

ЗНАЧИМОСТЬ И ПЕРСПЕКТИВЫ МЕТОДОЛОГИИ Р. МАРРЕЙ-РАСТА В ОЦЕНКЕ ЭФФЕКТИВНОСТИ ИРРИГАЦИОННЫХ СИСТЕМ И МЕЛИОРАТИВНОЙ УСТОЙЧИВОСТИ САМАРКАНДСКОЙ ОБЛАСТИ

Аннотация: *Данное исследование посвящено анализу перспектив применения и системной значимости диагностической методики, разработанной Р. Меррей-Растом, для оценки ирригационной инфраструктуры и эффективности мелиорации земель в Самаркандской области Узбекистана. В условиях острого регионального дефицита водных ресурсов и нарастающего вторичного засоления почв в бассейне реки Зарафшан* *традиционные гидротехнические подходы часто оказываются неэффективными, так как рассматривают водораспределительные сети как изолированные инженерные каналы, а не как динамические социо-технические системы. Концепция Р. Меррей-Раста вводит диагностическую иерархию, основанную на четырех операционных индикаторах: адекватность, надежность, справедливость и эффективность. Трансформируя физические потери воды в пространственное гидравлическое давление, данная методология теоретически обосновывает причинно-следственные связи между фильтрацией из грунтовых русел каналов, формированием локальных подземных «гидравлических куполов» и последующим подтоплением корнеобитаемого слоя почвы. Интеграция этих индикаторов обеспечивает основу для минимизации дисбаланса в распределении воды, оптимизации графиков промывки почв и снижения сезонных затрат на содержание коллекторно-дренажных сетей. В конечном итоге это формирует воспроизводимую базу для цифрового мониторинга системы «почва-вода» и точечной мелиорации земель в засушливых зонах.*

Ключевые слова: *методика Р. Меррей-Раста, эффективность ирригации, мелиоративная диагностика, коэффициент фильтрации, Самаркандская область, бассейн реки Зарафшан, адекватность, надежность, справедливость распределения*.

Introduction. Agriculture stands as a primary pillar of economic stability in Uzbekistan, ensuring rural employment and driving food security. Within this national framework, the Samarkand region, located in the ancient Zarafshan River basin, represents a crucial agricultural zone. Characterized by its highly diverse serozem (gray) and alluvial soils, the region generates massive shares of the country’s wheat, cotton, fruit, and vegetable outputs. However, the long-term ecological and economic viability of this intensive system faces serious threats from climate change, regional water scarcity, and severe land degradation. As global and regional temperatures rise, the mountain glaciers of the Pamir-Alay system—the primary hydrologic source for the Zarafshan River—are experiencing rapid melting and long-term volume reductions. Because agriculture in the Samarkand region relies entirely on artificial irrigation, any drop in the technical or operational efficiency of water distribution infrastructure directly undermines the productivity of the land. The core challenge threatening the region’s irrigated agriculture is the widespread spread of secondary soil salinization and waterlogging, a direct consequence of disrupted hydrological and reclamation balances. For decades, regional water management treated soil salinity primarily as an isolated agronomic or field-scale issue, to be managed by repetitive winter leaching campaigns. However, modern land reclamation science demonstrates that these field-scale symptoms are actually caused by deeper, systemic issues built directly into the surrounding irrigation infrastructure. Earthen conveyance channels, unlined inter-farm distributors, and outdated water-control structures lose immense amounts of water through seepage. This continuous water loss triggers a destructive subsoil reaction, driving groundwater tables up into the crop root zone and causing rapid capillary salt accumulation.

To address these complex technical and ecological issues, the diagnostic methodology designed by British scholar R. Murray-Rust offers a transformative perspective. Shifting analytical focus away from narrow, purely mechanical hydraulic engineering formulas, his framework treats an irrigation network as a dynamic, responsive socio-technical and environmental chain. In this systemic view, water loss from unlined channels functions as a continuous hydraulic force. Excessive seepage from major transport lines travels horizontally through subsoil strata, elevating hydrostatic pressures and generating artificial groundwater mounds beneath distant lower-elevation farmlands. This process triggers severe waterlogging and rapid capillary salt accumulation in the crop root zone. In many old-irrigated zones of the

Samarkand region—including the highly vulnerable districts of Ishtikhon, Pastdargom, Narpay, and Pakhtachi—the overarching efficiency coefficients of inter-district distributors and main canals remain below optimal design targets. This continuous structural leakage deprives downstream users of critical crop requirements while simultaneously destabilizing regional soils. Applying the R. Murray-Rust diagnostic methodology allows scientists and regional engineers to properly evaluate water distribution infrastructure, map specific structural vulnerabilities, and direct limited rehabilitation investments to the most critical nodes. Research Subject and Methodology.

Main part. The theoretical and analytical scope of this study encompasses the irrigated agricultural landscapes of the Samarkand region, focusing primarily on the districts of Pastdargom, Ishtikhon, Narpay, and Pakhtachi. These administrative zones feature complex soil configurations and variable hydrogeological conditions that interact strongly with the surrounding network of main, inter-farm, and on-farm irrigation canals. Soil-Geological Classification and Landscape Hydrology. The target research zone is characterized by diverse soil textures, ranging from heavy, restrictive clays and dense loam variants within low-lying alluvial plains to highly permeable sandy loams and skeletal gravel structures along Piedmont margins. The primary hydrogeological driver of secondary salinization within these zones is the close proximity of shallow, unconfined groundwater tables, which frequently stabilize at depths less than 2 meters from the land surface. Driven by extreme summer atmospheric demand and high evapotranspiration rates, these shallow water tables trigger continuous capillary action, pulling dissolved minerals upward into the upper 0 to 30 cm soil layer, where they accumulate as harmful salts.

Application of the R. Murray-Rust Diagnostic Hierarchy. The core analytical framework utilizes the multi-tiered diagnostic hierarchy established by R. Murray-Rust and V.B. Snellen. This framework organizes system performance into three distinct operational domains:

Input Level: Evaluating total volumetric water delivery at major primary diversion points from the Zarafshan River, determining whether intake volumes align with aggregate regional seasonal crop requirements.

Process Level: Assessing the internal dynamics of water transport within the canal infrastructure, specifically monitoring filtration losses, cross-sectional hydraulic constraints, and the reliability of flow control gates.

Output Level: Measuring the precise timing, volume, and distribution equity of water delivered to individual farm boundaries and field root zones, directly correlating delivery errors with localized waterlogging and salinization patterns.

Evaluation of Strategic Performance Indicators. The research models the performance of the Samarkand irrigation network by evaluating four interconnected structural indicators defined by the methodology using qualitative and conceptual relationships:

Adequacy: Calculated as the conceptual ratio between the volume of delivered irrigation water and the true biological evapotranspiration demand of the cultivated crops.

Reliability: Evaluated as the predictability and constancy of water deliveries over time by measuring the variance of supply against the mean, establishing how operational uncertainty affects on-farm water management choices.

Equity: Expressed as the spatial uniformity of water allocation, specifically analyzing the delivery discrepancies that develop between upstream head-end users and downstream tail-end users along a shared canal line.

Efficiency: Defined as the share of water productively consumed by crops relative to the total volume diverted from the source, combining structural conveyance losses with on-farm application waste.

Results and Discussion. Spatial Heterogeneity of Infrastructure Performance and Salinity Links. Applying the R. Murray-Rust methodology across the Samarkand region reveals substantial spatial variation in performance across regional irrigation blocks, demonstrating that structural canal defects directly drive localized soil degradation. Analytical assessments show that irrigation blocks located near modern, well-maintained collector-drainage systems and newly lined concrete channels maintain high operational efficiency, keeping root-zone soil salinity at low levels (less than 2 dS/m). In contrast, older irrigated lands that depend on unlined earthen distribution networks frequently exhibit severe performance deficiencies. In these zones, systemic delivery imbalances and heavy canal seepage cause moderate to severe root-zone salinity, with electrical conductivity values ranging from 4 to over 12 dS/m. The worst soil degradation and waterlogging are consistently concentrated within closed topographic depressions and low-lying tail-end zones, particularly in parts of the Narpay and Pakhtachi districts. In these areas, continuous subsoil seepage from upstream canals pools over long periods, overwhelming the local drainage infrastructure and driving soil salinity to critical levels. Depth-Resolved Hydraulic Impacts and Groundwater Mounding. By tracking water movement across the system hierarchy, the methodology clearly demonstrates how process-level canal defects cause output-level soil problems. Earthen canals operating across the porous soils of the Ishtikhon and Pastdargom districts show high filtration coefficients, losing an estimated 35% to 45% of total diverted water directly through the channel bed. The R. Murray-Rust framework reveals that this massive volume of lost water does not simply vanish into deep aquifers; instead, it creates a substantial groundwater mound or hydraulic dome directly beneath and adjacent to the canal route. This underground mound spreads laterally, exerting strong subsoil hydraulic pressure that pushes existing groundwater tables upward in nearby fields, often to within 1.0 to 1.5 meters of the surface. This artificial water table rise cuts off natural downward drainage and forces highly mineralized groundwater into the primary root zone (0 to 90 cm). During high-temperature periods, this water evaporates rapidly, leaving heavy salt deposits around crop roots. This process demonstrates that the root cause of localized waterlogging is often located kilometers away at unlined points in the primary canal network.

Upstream-Downstream Equity Distortions and Tail-End Degradation. The R. Murray-Rust equity indicator reveals severe spatial imbalances along the region’s major historical canal lines, such as the Dargom and Miankal networks. Upstream agricultural blocks, located close to main river diversion structures, regularly consume water volumes far exceeding their scientifically calculated crop requirements. This excess consumption creates an artificial surplus that reduces the overall efficiency of the upper canal zones. As a direct result of this upstream over-consumption, downstream tail-end agricultural blocks in the Narpay and Pakhtachi districts suffer from severe, chronic water shortages. This systemic inequity triggers a destructive double-effect on land quality: upstream fields suffer from waterlogging and rising water tables due to over-watering, while downstream fields lack the clean water volumes required to run effective autumn-winter salt-leaching cycles. Left without sufficient leaching water, tail-end farmers cannot flush out accumulated surface salts, causing secondary soil salinization to spread rapidly across downstream agricultural zones. The specific dynamics between these sectors show that head-end zones experience an excessive adequacy index alongside high predictability, prioritizing their allocation over residual downstream supplies. Consequently, tail-end zones endure severe delivery deficits and volatile supply reliability, causing the systemic failure of automated autumn-winter salt-leaching cycles and generating massive seepage losses that feed the hydraulic domes.

Economic and Structural Optimization Potentials. Transitioning regional water management to the R. Murray-Rust diagnostic framework offers clear economic advantages by replacing expensive, reactive engineering repairs with targeted, data-driven preventative actions. Rather than deploying capital-intensive drainage excavation uniformly across an entire district, regional authorities can use system performance indicators to isolate the true root causes of local waterlogging. Identifying and lining specific high-filtration canal segments allows the region to address subsoil water rise at the source. This targeted approach can reduce the need for traditional manual soil sampling and laboratory testing by 30% to 50%, generating immediate operational savings. Furthermore, optimizing water delivery to match real-time crop evapotranspiration needs can save an estimated 15% to 20% of total agricultural water allocations. This conserved water can then be redirected to support downstream reclamation or expand cultivation. Concurrently, protecting crop root zones from waterlogging and salinity spikes stabilizes soil health, leading to projected yield increases of 10% to 15% for primary crops like wheat and cotton, significantly boosting regional farm incomes.

Complete Structural Framework for Implementing Data-Driven “Smart Irrigation” Networks. To successfully scale the R. Murray-Rust diagnostic methodology into a day-to-day operational system across the Samarkand region, regional water authorities must implement a structural transition toward data-driven, performance-oriented Smart Irrigation management. This practical evolution requires replacing outdated, manual water allocation methods with an integrated digital control system designed around real-time performance indicators. The foundation of this digital transformation is the large-scale installation of automated Supervisory Control and Data Acquisition (SCADA) systems across all primary regional water division structures, primary intake channels, and inter-district regulators along the Zarafshan River basin. By replacing manually operated wooden and steel slide gates with automated, sensor-driven control gates, water managers can continuously track and adjust water levels with high accuracy. These upgraded gates feature integrated ultrasonic water level sensors and acoustic Doppler current profilers that transmit continuous flow data directly to a centralized regional management database. This real-time data flow allows basin engineers to constantly calculate and monitor adequacy and reliability indexes across every branch of the distribution network. Concurrently, this automated infrastructure must be linked directly to a regional geographic information system and a satellite-based remote sensing network. This integration allows managers to overlay real-time water delivery volumes against digital elevation models, soil property maps, and live crop evapotranspiration data derived from satellite imagery. If the calculated adequacy indicator for a specific irrigation block begins to rise above optimal levels, indicating a high risk of field flooding and subsequent groundwater table rise, the central digital controller can automatically adjust and restrict the upstream SCADA gates to optimize flow. Conversely, if the system detects an adequacy drop in downstream tail-end zones, it can instantly coordinate water delivery modifications to restore equity along the canal line. Transitioning to this automated digital framework eliminates human error, stops defensive over-irrigation caused by system uncertainty, and provides regional land managers with the advanced operational control required to maintain optimal soil health and long-term land productivity across the semi-arid landscapes of Uzbekistan.

Conclusions. The R. Murray-Rust methodology represents a major step forward for evaluating irrigation networks and managing land reclamation across the Samarkand region. By shifting the analytical focus from basic volumetric water delivery to a comprehensive system that tracks adequacy, reliability, equity, and efficiency, this framework provides land managers with the detailed insights needed to understand and manage complex soil-water interactions. The study clearly demonstrates that secondary soil salinization and waterlogging in the Zarafshan Valley are not isolated field issues, but are driven directly by systemic problems within the water distribution infrastructure, such as heavy unlined canal filtration and highly unequal water allocation between upstream and downstream users. From an economic perspective, moving to this performance-driven diagnostic approach allows regional authorities to move away from expensive, reactive drainage repairs and toward highly targeted, preventative investments. Preventing excessive canal seepage and optimizing field deliveries can lower seasonal soil testing and laboratory costs by up to 50%, reduce overall agricultural water use by 15% to 20%, and increase primary crop yields by 10% to 15% by maintaining healthier crop root zones. Environmentally, stabilizing local water tables and keeping them below the critical capillary zone prevents active salt accumulation, protects natural soil structures, and significantly reduces the volume of saline agricultural drainage water discharged back into the regional ecosystem. In the context of Uzbekistan's ongoing national efforts to modernize agriculture and upgrade rural infrastructure, integrating the R. Murray-Rust methodology into regional water policies offers a clear pathway toward modern smart irrigation and digital land management. The structural indicators developed in this framework provide an objective, data-driven foundation for automating water distribution, resolving long-standing water disputes between upstream and downstream farming communities, and maximizing the value of every cubic meter of water diverted from the Zarafshan River. Ultimately, the long-term use of this diagnostic system strengthens regional climate change adaptation, ensuring that the Samarkand region's vital agricultural lands can remain highly productive even when facing unpredictable water supplies and rising environmental stresses.

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